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INVESTIGATION OF BEDLOAD TRANSPORT OF CONTAMINATED GRAVEL IN
THE WHITE OAK CREEK DRAINAGE

SUMMARY REPORT

SUBCONTRACT NO. 19X-27463 C

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THURE E. CERLING
DEPARTMENT OF GEOLOGY AND GEOPHYSICS
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INTRODUCTION

As part of project ONLKGO2 (Environmental Restoration and Facilities Upgrade Task) it is necessary to adequately characterize the state of contamination of the White Oak Creek drainage basin. Such a characterization would yield information on the status of the active or residual nature of contamination for radionuclides, metals, and organic compounds in the watershed. The present subcontract involved several tasks to begin such a characterization study. These included: 1] participation in the overall planning of a streambed gravel survey program; 2] field operations to gather samples and obtain chemical analyses of contaminants present; and 3] evaluation of the recovery of streambed gravel samples of Melton Branch from prior contamination.

These tasks have been accomplished in the past year. Details of some of these issues have been dealt with in previous quarterly reports (14 October, 1985; 15 January, 1985; and 15 April, 1985). The present discussion will summarize the material contained in the previous reports and will provide new interpretations of data based on information received since the 15 April report.

Strategies were explored to determine the nature of contamination in the White Oak Creek watershed. For radionuclides, a survey of the radionuclide content of gravel throughout the basin was undertaken; active adsorption of radionuclides onto gravel in streams was studied; and occasional water samples were collected. For metals, similar studies to those above were undertaken. For organic compounds, both gravel samples and organic oozes were collected from a number of localities.

It has been shown previously that gravels can be used to provide information concerning the nature of contamination in streams (Spalding and Cerling, 1978; Cerling and Spalding, 1981, 1982; Cerling and Turner, 1982), because of the high distribution coefficients for adsorption onto a gravel substrate. In some cases, such as ^{90}Sr , this is a true distribution coefficient and the concentration of the radionuclide in water can be back-calculated from the

concentration of the gravel and an accurate distribution coefficient. In other cases, such as for ^{137}Cs , adsorption onto gravel is irreversible. While it is not possible to calculate water concentrations from knowledge of sediment concentrations, this radioisotope is very useful in detecting sporadic sources of contamination. ^{60}Co behaves in a manner between those mentioned above: in oxidizing portions of streams it is highly retained by gravel because of adsorption into actively forming manganese minerals that precipitate on the surface of the gravel substrate; however, in reducing portions of streams the coatings are dissolved, releasing ^{60}Co . In addition, abrasion of the gravel coatings causes ^{60}Co remobilization. Thus, the behavior of ^{60}Co in streams should be treated as a spiraling effect.

This study is concerned with the behavior of other elements as well. It is of interest to determine if toxic metals such as As, Cd, Cu and Pb, and organic contaminants represent an environmental hazard at ORNL. It is the purpose of this study to determine if contamination of the watershed by radionuclides, metals, or organic compounds is active or residual. In addition, this study is made in order to rank the sources of active contamination so that appropriate measures can be made. This study can then serve as a baseline to show the present state of contamination in the watershed and to show the present rates of contamination. Future studies can use this survey as a baseline for comparison to determine if any remedial measures were successful. Once successful remedial actions have been taken, continued monitoring of the system will allow projections of the time necessary for recovery of the sediment system.

PLANNING OF SURVEY PROGRAM

The survey program for contaminants at ORNL has two components: first to determine the present state of contamination in the basin; and second to design a suitable plan to study the recovery of the watershed following the implementation of procedures designed to alleviate active contamination problems. The second part of this program can be undertaken once the first part is satisfactorily completed.

The scheme to determine the present state of contamination in White Oak Creek drainage is outlined below. It is expected that some of these results will require additional research before complete characterization of the watershed can be made.

General considerations. In 1977 to 1979, several important surveys of sediments were carried out to characterize the behavior of radionuclides in the White Oak Creek watershed (Spalding and Cerling, 1979; Cerling and Spalding, 1981, 1982; Cerling and Turner, 1982). Those studies formed much of the basis for the survey carried out in 1985. In summary, those studies showed that distribution of radionuclides and metals in sediments is size dependant (Figure 1). This is a result of the different distribution of minerals as a function of size within sediments: quartz, which has a low distribution coefficient for adsorption of any substance, is most abundant in the sand to coarse silt fraction (250 microns to 40 microns) of stream sediments derived from the Conasauga shale. This comes about because of the fundamental nature of weathering. All rocks can weather in only two ways: by chemical processes or by physical processes. Rocks such as shale contain clay minerals, quartz, and feldspar as the dominant phases. Physical weathering results in a continuum of sizes of aggregate particles; in addition, individual mineral grains become separated to form individual particles. In shales, quartz and feldspar are most often of a medium sand to silt size, whereas individual clay particles are dominantly less than 10 microns in size. Thus, the medium sand to coarse silt sizes are dominated by quartz and feldspar grains. Thus, in a

setting where shale is a dominant contributor to the sediment load, the clay mineral fraction is likely to be distributed in both the coarse (gravel) and fine (silt and clay) size fractions.

Chemical weathering results in the dissolution of minerals; however, in certain cases, this in turn results in the precipitation of other phases. The iron and manganese cycles in the hydrologic system are strongly controlled by such processes. Iron and manganese are more soluble in waters with low dissolved oxygen such as groundwater; groundwater discharge into more oxidized streams such as White Oak Creek results in oxidation of the iron and manganese which then precipitate as a hydrous iron or manganese oxide phase, most likely goethite or birnessite/todokorite. In general, these form coatings on minerals of any size, although they are especially concentrated in the very fine fraction (less than 25 microns). Hydrous Fe-Mn oxides have very high adsorption coefficients for heavy metals; thus, metals are expected to be associated with the fine size fraction in sediments.

The other important constituent in the bedload of rivers is the organic fraction. Natural solid organic constituents have high distribution coefficients for dissolved organic compounds. Thus, they represent the most appropriate substrate for studying the organic contamination in the system.

Thus, to study the state of contamination of streams in the White Oak Creek watershed, it is necessary to examine several different components of the bedload. Radionuclides are associated with the clay mineral fraction, heavy metals with the Fe/Mn hydrous oxide fraction, and organic compounds with the organic fraction. In addition, it is desirable to characterize the sediments to be analyzed so that they can be readily compared from site to site to establish their relative importance. Unfortunately, it is not equally easy to separate out each of these components in the field. Because the relative abundances of different phases is so size dependent, it would be most ideal to study only a single size range. Because clay minerals are concentrated in both the coarse and the fine size range it is possible to easily isolate a fraction that has a high radionuclide content. In this survey, the 2.0 to 3.3 mm size fraction was used because it is easily isolated in the field by wet sieving. Metals are likely to

be concentrated in the fine size fraction, but are expected to be correlated with the Fe/Mn content. Organic contaminants are expected to be adsorbed onto organic substrates, so that samples with high contents of organic carbon are most favorable for studying the nature of organic contamination.

In addition, it is desired to be able to establish the nature of active versus residual contamination: while the bedload of a stream may be contaminated, it is important to know if contamination is continuing in that locality. This can be accomplished by conducting experiments that will show if contamination is continuing. Ideally, an uncontaminated substrate with high adsorption capacity can be placed in the stream. After a suitable length of time, the sample can be collected and analyzed. This analysis should determine if contamination is continuing.

An ideal survey of contamination would include a complete characterization of stream water. Unfortunately, an adequate characterization is logistically very difficult. This comes about primarily because of the intermittent nature of contaminants in the stream itself, so that a single or even multiple sampling is insufficient for characterization. This cannot be overcome by the use of continuous samplers unless they include an adequate filtering system and are acidified. The "dissolved" load of waters is considered to be that which passes through a 0.45 micron filter while the suspended load makes up that fraction larger than 0.45 microns. Even this results in some ambiguity for analyses of elements which may be present as a colloidal phase (e.g., Al which requires a 0.1 micron filter). Acidification is required to prevent formation of Fe/Mn phases which may sequester contaminants of interest. Thus, while it is desirable to have continuous characterization of water chemistries, it would be extremely difficult to do this in more than a few sites. It is more important to characterize a few waters at several different times to attempt to estimate the variability and the average background level. Unfortunately, this may not pick up any "spikes" of contamination.

Procedure for 1985 characterization. Important branch points within the White Oak Creek drainage were chosen for characterization. These included junctions of major

sites were chosen to see if active Fe-Mn deposition was taking place. Previous studies (Cerling and Turner, 1982) showed that deposition rates up to $2 \text{ mg-cm}^{-2}\text{-yr}^{-1}$ for Fe-Mn oxides occurred in the White Oak Creek Drainage. To further quantify the effects of Fe-Mn oxides in the contamination picture, glass beads (pyrex, 3 mm average diameter) were placed in slotted well casing and collected after one month. Table 1 shows the studies conducted at each of localities shown in Figure 2.

The bulk of the radionuclide analyses, analysis of metals and other inorganic species, and analyses of organic species were carried out by T.G. Scott, B.R. Clark, and J. Caton, respectively, all of the Analytical Chemistry Division, Oak Ridge National Laboratory. In addition, a few radionuclide analyses were conducted by I.L. Larson (Environmental Science Division, Oak Ridge National Laboratory). Petrographic, SEM, and some chemical analyses were also conducted in the principle investigator's laboratory at the University of Utah with the assistance of D. Ackerman and C. Pittlekow.

STATUS OF CONTAMINATION OF WHITE OAK CREEK SEDIMENTS

In this survey we examine the load carried by indigenous gravel in a number of localities that represent important branch points in the drainage network (Figure 2). The metal or radionuclide content of these gravels will be referred to as the **standing crop** and makes no implications concerning the active or residual nature of contamination. In addition, at 17 localities uncontaminated gravel was placed in the stream about 15 July and collected about 15 August. These gravels were then analyzed. The metal or radionuclide content of these gravels can be used to determine the active nature of contamination at that locality.

Desorption of radionuclides from sediments. Previously, Cerling and Turner (1982) showed that ^{60}Co was desorbed from gravels in a reducing environment over a period of several months while it was relatively immobile in oxidizing environments. This behavior resulted from its incorporation in manganese oxide coatings that form on surfaces in oxidizing portions of the stream and dissolve in reducing portions of streams. They also showed that most ^{90}Sr was rapidly exchanged with stream water and was desorbed from contaminated gravel placed in an uncontaminated portion of the stream. Desorption approximated a first order rate constant with a value of about 0.25 d^{-1} . This behavior results from cation exchange in the 12-fold layer of clay minerals. Some ^{90}Sr was also relatively strongly held, probably as a non-exchangeable cation in manganese oxide minerals. That study also showed that ^{137}Cs appeared to be firmly held and not lost when contaminated gravel was placed in an uncontaminated environment. This section explores this last issue because it has been implied in many studies that ^{137}Cs can be used as a particle tracer because of the irreversible nature of its adsorption. In addition, the present study implies that no indigenous gravel is allowed into the sample chamber used in the radionuclide uptake studies.

In August, 1985 several samples of contaminated gravel placed in the upstream uncontaminated portion of White Oak Creek in 1979 were collected. These samples had been deployed as part of the study reported in Cerling and Turner (1982). Analysis of the gravels

for ^{137}Cs showed that the only ^{137}Cs loss was due to radionuclide decay and that no detectable dilution of the sample occurred. This substantiates the assumption that the sampling program, which involves putting coarse gravel within a fine mesh and seiving out any fine material when recollecting the sample, does not result in contamination of the sample gravel by local indigenous gravel.

Choice of extractants for radionuclide and metal studies. When analyzing sediment for certain radionuclides or metals it is necessary to decide how best to extract a sample. It is possible to entirely dissolve the sample, or to extract some component of the sample that best represents the fraction of interest. It has been shown that metals associated with manganese oxide minerals in the marine and non-marine environment can be extracted with hydroxylamine-hydrochloride (e.g., Chao, 1972; Spalding and Cerling, 1981; Cerling and Spalding, 1982). Other workers have used nitric acid for a leach, while the Environmental Protection Agency (1984) uses an acetic acid leach to study metal mobility in sediments. In this study we evaluated three different extractants to determine which of them could be used to maximize the concentration ratio for an element for a contaminated versus an uncontaminated sample. Our three procedures were: a) 1 N HNO_3 leach; b) 2% $\text{NH}_4\text{OH}\cdot\text{HCl}$ in 0.3 M NH_3 -citrate at pH 7 leach; c) 0.5 N acetic acid (EPA Method 1310). Of these, the nitric acid leach in general extracted the most metal, the hydroxylamine hydrochloride was intermediate but with low backgrounds, and the acetic acid was relatively ineffective in leaching metals. Table 2 shows the results of comparing uncontaminated sediment gravels from one locality. Table 3 shows the relative effectiveness of the different extractants by calculating the ratios of concentrations in the contaminated versus uncontaminated sediments. This shows that while nitric acid was a more effective leach, it has a high background so that hydroxylamine hydrochloride is the more favorable leach to determine relative degrees of contamination.

Several water samples were collected to determine if the radionuclide content of filtered samples differed substantially from unfiltered samples. In most cases these values did not

differ significantly so that the radionuclide content of samples collected using the Manning sampler can be treated as the dissolved content.

Sample localities. Individual sample localities are shown in Figure 2; additional information on the samples collected and submitted to the Analytical Chemistry Division are given in Appendix 1. Table 1 briefly summarizes types of samples collected at each of the sites in Figure 2. The sites studied fall into three categories which are here termed primary sites, secondary sites, and stream profiles. Primary sites were chosen for more complete characterization than the secondary sites. Primary site studies include samples of indigenous gravel to be analyzed for the contaminant load, distribution coefficient determinations for indigenous gravels, mineralogic studies, uptake studies to determine the active nature of contamination, and chemical and radionuclide analyses of waters. It is hoped that these studies will provide the background for calculations of the contaminant flux from each site. Secondary site studies include only measurements of the contaminant load of indigenous gravels. Many of these sites did not have permanent water flow for the study period, or were selected because of particular problems posed by members of the ERFU group. Stream profiles were taken in two localities to study the details of the problem of radionuclide contamination and movement in streams.

Different lithologies dominate the bedrock in Bethel Valley and Melton Valley which are underlain primarily by the Chickamauga Limestone and Conasauga Shale, respectively. The two valleys are separated by the Rome formation which forms a prominent ridge. The dominant rock type in Bethel Valley is limestone and chert, whereas in Melton Valley shale is the dominant rock type. This has important effects on distribution coefficients for radionuclide sorption.

Sites were chosen for study because the 1978 survey of Cerling and Spalding (1981, 1982) showed that these had important levels of radionuclides in those drainages, or were free of radionuclides at that time. In this study we can compare the level of contamination in 1978 with that observed in 1985 with respect to ^{60}Co , ^{90}Sr , and ^{137}Cs . In 1985, 3 to 5

the net flux of ^{60}Co in the stream during the sampling interval; ^{90}Sr in gravels is in dynamic equilibrium with the water and thus can be used to calculate average concentrations of ^{90}Sr in water; ^{137}Cs is irreversibly adsorbed by the gravel and is a measure of the net flux of ^{137}Cs in the stream during the sample interval. It should be noted that the gravel chosen for this study has higher adsorption characteristics than gravels from other parts of the basin, especially those indigenous gravels in Bethel Valley.

Each of the 37 sites sampled is discussed below. Variation given is one standard deviation for the average of two or three samples. Some of the values given below will necessarily change as more data is compiled. Standard deviations reported for the samples labeled SORB result from counting statistics.

Figures 3, 4, and 5 show the uptake of ^{60}Co , ^{90}Sr , and ^{137}Cs , respectively during the study period. Table 4 shows the Cu, P, Zn contents of gravel after a residence time of one month at Sites 1 through 17. These species showed the greatest change during the one month observation period. Table 5 shows the amount of metals extracted by hydroxylamine hydrochloride for the indigenous gravels at each of the localities.

Site 1. Monitoring Station 3. Site 1 is located just south of Monitoring Station 3. Organic ooze was collected from the pond above the weir. This site serves as a measure of the contaminant flux of White Oak Creek above its confluence with Melton Branch. A Manning sampler was used 29 July to 15 August to estimate the daily variability in the radionuclide content of stream water at this site. Glass beads were deployed to study the rate of Fe/Mn deposition. Very little Fe-Mn accumulation was observed in the study period.

	year	^{60}Co (Beq/Kg)	^{90}Sr (Beq/Kg)	^{137}Cs (Beq/Kg)
gravel:	1978	3510 ± 160	205 ± 12	42000 ± 1000
	1985	1290 ± 280	280 ± 60	32000 ± 4000
	SORB	110 ± 20	350 ± 40	7700 ± 500
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n = 17	$0.55 \pm .25$	4.8 ± 1.4	3.6 ± 3.3

From the data shown is quite evident that major active contamination is present above Monitoring Station 3. From the SORB sample it is clear that active ^{137}Cs contamination is taking place; the contamination can be traced upstream to Site 12 and is probably related to direct plant effluent from the ORNL complex. Interestingly, the standing crop of both ^{60}Co and ^{137}Cs is significantly lower than it was in 1978 probably indicating reduced radioactive effluent during the intervening period. ^{90}Sr is about the same as it was in 1978. The SORB sample has a higher distribution coefficient for ^{90}Sr adsorption and thus has a higher ^{90}Sr concentration than does the indigenous gravel. Water samples taken at this locality show that the radionuclide discharge is sporadic: ^{60}Co , ^{90}Sr , and ^{137}Cs values in stream water at this site vary between .2 and 1.2 Beq/L, 3.2 and 8.4 Beq/L, and 0.7 and 10.0 Beq/L, respectively during the period of study (15 July, 1985 to 15 August, 1985).

Site 1 shows a significant change in the Zn content of SORB gravel after a period of one month residence in the creek (Table 4). All sites on White Oak Creek below the cooling facility (south of 4500S) show elevated Zn levels. Water samples collected from this locality had detectable Zn levels (1.0 micromole per liter). In addition, indigenous gravels showed higher Cd, Cr, Cu, Mo, P, and Zn than background samples (Table 5). It is most likely that these metals are associated with plant effluent release from the main ORNL plant complex, probably cooling water release.

Site 2. Monitoring Station 4. Site 2 is located downstream from Monitoring Station 4. Organic ooze was collected from the pond above the weir. This site serves as a measure of the contaminant flux of Melton Branch above its confluence with White Oak Creek. A Manning sampler was used 29 July to 15 August to estimate the daily variability in

per liter). In addition, indigenous gravels showed high levels of extractable Cr, (Cu?), (Mo?), P, and Zn. These are traceable to HFIR, NSPP, or MSRE.

Site 3. Monitoring Station 4A. Site 3 is located below Monitoring Station 4A. Organic ooze was collected just above the weir. This site characterizes the contribution of the HFIR complex to Melton Branch.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	27000 ± 6000	<10	250 ± 90
	1985	27000 ± 7000	<10	130 ± 40
	SORB	4000 ± 300	<10	26 ± 18
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n=3	1.5 ± 1.7	<.2	<.2

Monitoring Station 4A shows important levels of active contamination by ^{60}Co . These can be traced upstream to the HFIR cooling water effluent. Virtually no contamination of ^{90}Sr was detected in this drainage; Cerling and Spalding observed this in the 1978 survey. Only minor ^{137}Cs contamination is present. Several water samples showed that the ^{60}Co levels were variable, which is similar to the findings at Monitoring Station 4. This contamination results from the active discharge of HFIR.

This site also shows active Zn contamination which can be traced to the HFIR facility. Indigenous gravels also show high levels of extractable (Cd?), Cr, Cu, Mo, P, and Zn which are traceable to HFIR.

Site 4. Monitoring Station 4B. Site 4 is located at Monitoring Station 4B. Fine grained organic material was collected to characterize the organic contaminants. This site characterizes HRT settling basin, NSPP, and MSRE. It is located above the groundwater discharge from (SWSA) 5. The difference between Site 2 and Sites 3 and 4 ([Site 2] - [Site 3 + Site 4]) should represent the contribution of SWSA 5 to Melton Branch.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	22 ± 20	2180 ± 388	44400 ± 18000
	1985	57	1200	16000
	SORB	<3	980 ± 60	290 ± 20
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n=2	<.2	14 ± 1	<.2

The site as Monitoring Station 4B shows active contamination by ^{90}Sr . However, although its highest level of contamination is due to ^{137}Cs , this appears to be predominantly residual in nature. It appears that this source of ^{137}Cs has diminished in the past decade. It should be pointed out that the observed level of contamination of the gravel is less than would be expected if loss were due only to radioactive decay of ^{137}Cs . Because ^{137}Cs is so strongly sorbed to gravel in this part of the watershed, it is likely that the lower level of ^{137}Cs contamination results from dilution of gravel caused by bedload transport and the generation of new gravel by bank caving.

^{90}Sr in the stream is quite high at this locality and possibly represents seepage from the HRT settling basin.

No appreciable metal uptake was observed after one month. However, indigenous gravels had above background levels of Cr, Cu, P, and Zn (Table 5). These levels can most likely be attributed to effluent release from NSPP and MSRE. Note, however, that the Zn levels are still an order of magnitude lower than associated with cooling water releases from the ORNL complex and from HFIR.

Site 5. At weir on creek leading to Pits 2, 3, and 4 and Trench 5. Site 5 is meant to characterize leakage from these disposal sites.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	45000 ± 19000	45 ± 8	990 ± 440
	1985	13000 ± 2000	19 ± 62	60 ± 100
	SORB	120 ± 10	<10	<5
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n = 2	29 ± 1.4	$.3 \pm .1$	<.2

Site 5 requires some additional investigation. ^{137}Cs and ^{90}Sr contamination are minimal. However, analyses of water samples indicate significant ^{60}Co contamination while the SORB gravel samples indicate that ^{60}Co is an insignificant problem. This could be due to the nature of the sampling site. This locality rarely had running water present although water often collected behind the weir. The SORB sample was suspended in this pool. During periods of high flow, this water was oxygenated, whereas during periods of low flow the oxygen content of the water was quite low. Previous studies (Cerling and Turner, 1982) showed that ^{60}Co is released from hydrous manganese oxide coatings when the dissolved oxygen content of the water is low. It is likely that such was the case at this locality. Both water samples were collected at low flow when only standing water was present. Thus, probably neither the gravel nor the water collected at this site is representative of the degree of contamination by ^{60}Co because both are variable due to changing redox conditions.

However, the ^{60}Co content of indigenous gravels collected from this locality were not in the pool of water behind the weir and show lower levels of ^{60}Co contamination in 1985 than in 1978. This could be due to the remedial actions taken on some of the pits and trenches in the intervening time (Spalding and Boegly, 1985) although this study is not comprehensive enough to determine if this is the case.

Cr, P, and Zn showed slightly higher than average values, although significantly below that for White Oak Creek and Melton Branch.

Site 6. Weir on creek east of SWSA 6. Site 6 can receive groundwater discharge from Pits 1, 2, 3, and 4, and from the east side of SWSA 6.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	13100 ± 1500	600 ± 55	135 ± 115
	1985	2600 ± 100	240 ± 30	115 ± 40
	SORB	49 ± 7	100 ± 20	5 ± 3
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n = 2	7 ± 7	2.8 ± 1	$< .2$

Site 6 has some of the same problems as site 5: the weir acts as a dam that collects pools of reducing water during periods of low flow. In any case, ^{90}Sr and ^{137}Cs contamination is low. The interpretation of the ^{60}Co data is ambiguous because of the problems of the changing redox potential of water at this site. However, the significantly lower level of ^{60}Co from the indigenous gravels in 1985 as compared to 1978 is encouraging and reflect remedial actions taken on the Pits and Trenches in the intervening years (Spalding and Boegly, 1985).

Extractable P was slightly above background levels; other metals were at about background levels.

Site 7. SWSA 6. Site 7 is located at the monitoring station in SWSA 6. Earlier surveys in 1978 showed that significant ^{90}Sr was present in this creek (Cerling and Spalding, 1981, 1982).

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	2700±450	22±16
	1985	<5	820±120	18± 2
	SORB	<5	190± 30	<5
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n = 2	<.2	3.9±1.3	<.2

The stream on the western end of SWSA 6 had contaminated sediments in 1978 (Spalding and Cerling, 1979). This was shown to be due to a seep from one of the trenches in SWSA 6. Since then considerable activity has centered on problems of fracture flow in that area. This survey indicates some possible improvement in conditions since 1978: the indigenous gravel has a much lower ^{90}Sr load in 1985 than it had in 1978. This could be due to the various treatment programs. It is also possible that the 1985 sampling was during a period of low radionuclide concentration, although it is probably not likely. Some discussion is needed for the lower concentration of ^{90}Sr in the SORB sample as compared to the indigenous gravel because both have approximately the same distribution coefficient for ^{90}Sr . This could result from the different conditions at the collection sites for the SORB sample and for the indigenous gravel sample. The former was placed in a permanent pool of water at the

small weir on the creek and was in permanent water for the entire month of study; the latter was in an ephemeral portion of the stream and was in water probably only about 20 percent of the study period.

Extractable metals were all about at the average levels for this locality.

Site 8. Monitoring Station 2. Site 8 is located at Monitoring Station 2 on White Oak Creek. A previous survey showed that only slight contamination was present at this locality in 1978.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	15 ± 14	23 ± 8	120 ± 55
	1985	87	12	180
	SORB	<5	23 ± 10	10 ± 2

Monitoring Station 2 was chosen for characterization because the earlier survey in 1978 showed little contamination. The situation has not changed significantly since that time.

Extractable Cd, Cr, Cu, Mo, P, and Zn were all above background levels and may be associated with cooling water discharge.

Site 9A. Upper weir on SWSA 4 creek. Site 9 is located at the upper monitoring station of the creek south of SWSA 4. Only slight flow occurred during the study period; however, active Fe-Mn precipitation was noted during the study period. The lower monitoring station near the confluence with the Old White Oak Creek channel had no flow for most of the study interval. Several pieces of plate glass were collected: they had been deployed in 1979 as part of an earlier study (Cerling and Turner, 1982) and had a significant Fe-Mn coating.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	253 ± 96	28000 ± 2200	5870 ± 1200
	1985	160 ± 30	17000 ± 13000	5400 ± 400
	SORB	<5	9800 ± 200	54 ± 7
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n = 3	<.2	350 ± 50	<.2

SWSA 4 has been long known to have contaminated sediments present in the creek south of the area. The contaminant load of sediments in the creek has changed little since 1978. The SORB sample was on the upstream end of the interval sampled for the indigenous gravel which shows a strong increase in ^{60}Co and ^{137}Cs . This probably indicates a source rich in ^{60}Co and ^{137}Cs just downstream of the place chosen for the SORB experiment. Although the concentrations of ^{90}Sr on gravel (and by analogy in the stream water) are relatively unchanged since 1978 it is likely that the total discharge from SWSA 4 has dropped because of construction of the french drain above SWSA 4.

Extractable Mo and Ni are elevated above background levels. This is especially the case for Ni, which for three samples averages about 100 times the background level.

Site 10. White Oak Creek. Site J north of Bethel Valley Road. Site 10 is located north of Bethel Valley road and is intended to serve as a background station. The locality (JK) is the same as that used by Cerling and Turner (1982) to study radionuclide release by contaminated sediments. It is an active site of Fe-Mn precipitation. Glass beads were deployed at this locality. Several pieces of plate glass deployed in 1979 were collected from this locality. Organic rich ooze was collected from below the culvert under the gravel road near this locality. Clams were deployed at this locality in conjunction with G. Southworth.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	<10	<5
	1985	<5	<10	<5
	SORB	<5	<10	<5
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n = 1	<.2	<.2	<.2

This site was chosen as a background station for Bethel Valley. It is above any likely radionuclide or metal contamination sources and has background values for extractable metals.

Site 11. White Oak Creek at cooling tower (bldg. 4500S). Site 11 is located at the eastern bridge leading from Building 4500S to the cooling towers. The 1978 survey showed no contamination at this locality. Organic rich ooze was collected several meters upstream of the bridge.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	<10	<5
	1985	<5	<10	<5
	SORB	<5	<10	<5

This site was chosen because the 1978 survey showed no evidence of radionuclide contamination. This has not changed in the subsequent period. Extractable Cr, Cu, Mo, P, and Zn are all well above the average values for this part of the watershed and are probably related to the active discharge of cooling water.

Site 12. White Oak Creek at the Third Street Bridge. Site 12 is located at the Third Street bridge across White Oak Creek. A previous survey in 1978 showed significant contamination by ^{137}Cs at this locality. Organic rich ooze was collected from behind a concrete structure in the water downstream from the bridge.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	3410 ± 2400	120 ± 67	22700 ± 4800
	1985	1700	100	30000
	SORB	160 ± 30	220 ± 30	26000 ± 2000

Site 12 was chosen because of its probable location near a radionuclide source based on the earlier study of Cerling and Spalding (1981, 1982). This turned out to be the case. The data show a high level of active contamination of ^{137}Cs and lesser amounts of active ^{60}Co and ^{90}Sr contamination. The higher distribution coefficients for ^{90}Sr and ^{137}Cs for the gravel used for the sorption experiment result in the higher levels of contamination for the SORB gravel after one month than for the indigenous gravel.

Extractable Cr, Cu, Mo, P, and Zn all above background values and are probably associated with cooling water effluent.

Site 13. Northwest Tributary at gauging station. Site 13 is located on the Northwest Tributary at the staff gauge. It is intended to characterize contamination from SWSA 3 and First Creek.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	53± 6	66±85
	1985	<5	280±40	370±50
	SORB	<5	510±40	49± 6

This site was chosen to characterize the contribution of sources in the Northwest Tributary. The data clearly show active contamination of ^{90}Sr in the stream waters of the tributary. There has been a significant increase since 1978 in the level of ^{90}Sr and ^{137}Cs in the indigenous gravels of the stream indicating perhaps a new source of contamination in the drainage. In 1978 the only source of ^{90}Sr was well upstream of site 13 and was located at site 20 of this study.

Extractable Cr, Cu, Mo, P, and Zn are above background levels and are probably associated with plant effluent.

Site 14. Monitoring Station 2A. Site 14 is located at Monitoring Station 2A. It is intended to characterize White Oak Creek above SWSA 4 and the contaminated floodplain east of SWSA 4. This site had little gravel in the bedload of the stream, probably because of construction activities. However, it is an important site for characterization of uptake rates. Clams were deployed at this locality. While they were alive on 12 August, they had expired by the time of collection of 19 August.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	926±450	191±12	13900±3860
	1985		no collection	
	SORB	150± 20	340±40	11000± 400

Site 14 was chosen to characterize contamination of White Oak Creek above the influence of contributions from SWSA 4. The data show active contamination of ^{60}Co , ^{90}Sr , and ^{137}Cs . The high variation in ^{60}Co and ^{137}Cs values in the 1978 survey was probably due to active construction in the area at the time of the survey.

Site 15. On tributary to Melton Branch: above HFIR confluence. Site 15 is located above the cooling water effluent from HFIR on the tributary to Melton Branch east of the HFIR complex. It should serve as a reference station for the state of contamination prior to the opening of the planned SWSA 7.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	<10	<5
	1985	<5	<10	<5
	SORB	<5	<10	<5

Site 15 was chosen because it was above the HFIR confluence and was uncontaminated with radionuclides in 1978. No observable changes have taken place in the interim.

Extractable metals are at background levels at this site.

Site 16. On tributary to Melton Branch: below HFIR confluence. Site 16 is located below the cooling water effluent from HFIR on the tributary to Melton Branch east of the HFIR complex. The 1978 survey indicated that this effluent was most likely to be the dominant discharge source of ^{60}Co from ORNL at that time (Cerling and Spalding, 1981, 1982). Radionuclide uptake studies conducted in 1979 (Cerling and Turner, 1982) showed that this source was active.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	29200±13300	48±15	232±70
	1985	41000	360	130
	SORB	3100± 200	<10	<6

Site 16 was chosen because it was actively being contaminated 1979 as suggested by Cerling and Spalding (1981, 1982) and confirmed by Cerling and Turner (1982). It is still a site of active contamination.

Extractable Cr, Cu, Mo, (Ni?), P, and Zn are above background levels and are associated with cooling water discharge from HFIR.

Site 17. On Melton Branch; above HFIR confluence. Site 17 is located on Melton Branch upstream from the confluence with the HFIR creek. It is the site chosen to

obtain uncontaminated gravel from the creek (SORB samples). This gravel is that used in the radionuclide uptake studies. It showed background levels of ^{90}Sr and ^{137}Cs .

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	<10	<5
	1985	<5	<10	<5
	SORB	<5	<10	<5
water:	1985	^{60}Co (Beq/L)	^{90}Sr (Beq/L)	^{137}Cs (Beq/L)
	n = 1	<.2	<.2	<.2

Site 18. First Creek. Site 18 is located on First Creek. It was sampled because of reports of observed contamination of the waters during February, 1985 (D.D. Huff). This is of interest because the 1978 survey showed only background levels.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	14 ± 8	21 ± 5
	1985	<5	580	12

Site 18 was chosen because of the possibility of a new contamination source in the Northwest Tributary portion of the basin which is documented by the observed higher levels of ^{90}Sr in the gravels in 1985 as compared to 1978. The location of the ^{90}Sr source is between Site 18 and Site 19 because only low ^{90}Sr contamination is observed at Site 19.

Extractable P and Zn are significantly above background levels.

Site 19. First Creek. Site 19 is on First Creek upstream from Site 18. It is hoped that Sites 18 and 19 will bracket the contamination source on this creek.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	15 ± 9	13 ± 12
	1985	<5	<5	12

This locality was not contaminated in 1978 and shows no evidence for major contamination in 1985. Thus the First Creek contamination source is between Sites 18 and 19.

Site 20. Northwest Tributary at seep. Site 20 is located on the Northwest Tributary at about the location of an observed contamination source for ^{90}Sr in the 1978 survey. This site showed a significant amount of green fluorescene dye on the date of observation (15 August, 1985) that had been injected several days previously in SWSA 3.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	3100	<5
	1985	<5	1000	12

Site 20 was chosen to characterize the seep on Northwest Tributary. One gravel sample was collected above the seep area; a second was collected below the seep area. This locality was contaminated in 1978 and is still contaminated. It is not known if the difference in ^{90}Sr content between the samples from the 1978 and 1985 surveys is significant since both samples were collected during a period of very low flow. It is expected that there is probably a large annual variation in the ^{90}Sr content for gravels from this locality.

Extractable metals were at background levels at this site.

Site 21. Northwest Tributary. Site 21 is located on the Northwest Tributary about 30 meters downstream from the road crossing. The 1978 survey showed this site to have low ^{90}Sr values, presumably because of downstream dilution. Taken together, Sites 18 through 21 are intended to provide surface information concerning the contribution of laboratory and SWSA 3 contamination to the surface waters west of the main ORNL complex.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	290	<5
	1985	<5	80	<5

This locality was contaminated in 1978 and is still contaminated. It is not known if the difference in ^{90}Sr content between the samples from the 1978 and 1985 surveys is significant since both samples were collected during a period of very low flow. Thus it is expected that there is probably a large annual variation in the ^{90}Sr content for gravels from this locality.

Extractable metals are at background levels at this site.

Site 22. Melton Branch immediately above HFIR confluence. Site 22 is located on Melton Branch just above the confluence with the HFIR tributary. It is part of a stream profile study.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	<10	<5
	1985	<5	<10	<5

This site was chosen because it is above all of the effluent from the HFIR facility. Site 15, while above the cooling water discharge from HFIR, is not above all HFIR effluents.

Extractable metals are at background levels at this site.

Site 23. Melton Branch at HFIR junction. Site 23 is located on Melton Branch just below the confluence with the HFIR tributary. It is part of a stream profile study.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	25500±12000	<10	360±170
	1985	25300± 5100	<10	140±100

Site 23 was chosen because it represents the first portion of Melton Branch that is contaminated with radionuclides. The high variation in ^{60}Co is due to the rapidly changing value of ^{60}Co sorbed in this portion of the stream which may result from the mixing of the cooling waters and the relatively cold waters of Melton Branch. Comparison of the 1978 and 1985 survey indicates that essentially no change has taken place during the sampling period.

Extractable Cr, Cu, Mo, P, and Zn are above background levels at this site and can be attributed to HFIR cooling water discharge.

Site 24. Tributary to MSRE facility. Site 24 is located on a tributary leading to MSRE. The 1978 survey showed some ^{90}Sr and ^{137}Cs contamination from this source.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	11±18	1090±194	294±66
	1985	20±8	363± 42	137±31

The 1978 survey showed significant levels of ^{90}Sr in this tributary. The 1985 level of contamination is quite a bit lower than the 1978 values. However, more samples need to be collected to determine whether or not this is a permanent or a transitory phenomena.

Extractable Cr, (Cu?), and P are above background levels at this locality. Zn is only slightly above background levels at this locality.

Site 25. Tributary at HRT settling basin. Site 25 is located above the confluence of the Site 24 creek and is east of the NSPP complex.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	65 ± 24	2475 ± 300	102000 ± 22000
	1985	31 ± 10	2430 ± 1710	40000 ± 6200

A considerable portion of ^{90}Sr arises from this locality. Immediately upstream, Sites 24 and 26 show only low levels of ^{90}Sr and ^{137}Cs contamination. ^{90}Sr appears to be unchanged from the 1978 level, although ^{137}Cs seems to be significantly lower. The fact that the SORB sample downstream from this locality (Site 4) shows little active ^{137}Cs indicates that the ^{137}Cs contamination in the area is probably residual. Since the ^{137}Cs contamination does not extend upstream to either the NSPP or MSRE facilities the original source was most likely the HRT settling basin which is no longer an active source of ^{137}Cs to the stream.

Extractable Cr and P are above background levels. Zn is only slightly above background at this locality.

Site 26. Tributary to NSPP, above Site 25. Site 26 is located below the confluence of the Site 24 and Site 25 creeks and is southeast of the HRT settling basin. The HRT settling basin was interpreted to be a significant ^{90}Sr and ^{137}Cs source in the 1978 survey. Taken together, Site 24, 25, and 26 are intended to show the relative contributions of the HRT, NSPP, and MSRE complexes to the total flux measured at Site 4.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	554 ± 320	44 ± 4	96 ± 173
	1985	413 ± 181	71 ± 25	167 ± 139

This site shows minor ^{60}Co contamination which is most likely active in nature. Radioactive decay of ^{60}Co should have lowered the ^{60}Co value of the gravels, and oxidation - reduction processes in the stream should have further reduced the ^{60}Co concentration on the gravel substrate. This site also has significant levels of ^{154}Eu (373 ± 152 Beq/Kg) and ^{155}Eu (58 ± 17 Beq/Kg) in the sediments.

Extractable P and Zn are slightly above background at this locality.

Site 27. Tributary to NSPP, etc. Site F of Cerling and Turner. Site 27 is located downstream from Monitoring Station 4B. It is located at Site F of Cerling and Turner (1982) and is a known site of active Fe-Mn deposition.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	1980 ± 530	27600 ± 3200
	1985	12 ± 3	1140 ± 500	20000 ± 7500

This site appears to have a lower ^{90}Sr and ^{137}Cs content in 1985 than in 1978. It is possible that this is simply due to the annual variations in the radionuclide content of the stream. However, the results from Sites 4 and 25 indicate that ^{137}Cs is probably no longer actively contaminating this stream.

Extractable metals are at background levels at this site.

Site 28. Melton Branch below NSPP tributary. Site 28 is located on Melton Branch below the confluence of the creek leading to HRT, NSPP, and MSRE. It is part of a stream profile study.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	43200 ± 10900	141 ± 12	1730 ± 1010
	1985	24000 ± 2000	210 ± 36	1360 ± 780

This site had somewhat lower ^{60}Co values in 1985 than in 1978. However, it appears that the 1978 values for this locality were anomalously high for that period when compared to samples upstream or downstream from this locality.

Extractable Cr, Cu, Mo, P, and Zn are above background at this locality. These contaminants are traceable to the HFIR cooling water effluent.

Site 29. Tributary to Trench 7. Site 29 is located on the ephemeral creek leading to the east side of Trench 7. Although this is a well-known ^{60}Co source as indicated by the high concentration of ^{60}Co in gravels near seeps from the trench (Means et al., 1978). Cerling and Spalding (1981, 1982) showed that the total flux of ^{60}Co from this source was probably considerably smaller than from the HFIR source.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	$366,000 \pm 215,000$	75 ± 45	1500 ± 500
	1985	130,000	600	<100

The level of ^{60}Co at this locality appears to be lower in 1985 than in 1978 although the variation in the 1978 samples was very high. However, with the relatively short half-life of ^{60}Co it is likely that contamination is lowered by the amount expected due to radioactive decay of ^{60}Co .

Site 30. Creek west of Trench 7. Site 30 is located on the ephemeral creek leading to Trenches 5, 6, and 7.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	4000 ± 1000	160 ± 150	420 ± 85
	1985	1600 ± 200	50 ± 10	265 ± 35

Contamination in 1985 is slightly lower than in 1978 and is probably due to the radioactive decay in the source region. This is particularly true for ^{60}Co .

Site 31. White Oak Creek below trench 7 confluence. Site 31 is located in White Oak Creek below the confluence of the creek leading to Trenches 5, 6, and 7.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
	1978	4290 ± 270	532 ± 140	49000 ± 18400
	1985	3200 ± 560	280 ± 14	50000 ± 3000

^{60}Co and ^{137}Cs values are not significantly different in 1985 than in 1978, although it appears that ^{90}Sr may be significantly lower for this stretch of White Oak Creek.

Extractable Cr, Cu, P, and Zn are above background at this locality and are primarily due to cooling water discharge from the main ORNL complex and from HFIR.

Site 32. Tributary leading to Pits 2 and 3. Site 32 is located on a tributary of the creek leading to Pits 2 and 3.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	240 \pm 100	600 \pm 405	183 \pm 110
	1985	470 \pm 80	98 \pm 12	240 \pm 35

This creek appears to have significantly less ^{90}Sr in 1985 than in 1978. Perhaps this may be attributed to remedial actions taken on the Pits in the intervening time (Spalding and Boegly, 1985).

Extractable metals are at background levels at this site.

Site 33. Creek leading to Pit 1. Site 33 is located on the tributary leading to Pit 1.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	745 \pm 215	66 \pm 54
	1985	<5	380 \pm 15	151 \pm 130

This creek appears to have significantly less ^{90}Sr in 1985 than in 1978. Perhaps this is attributable to the paving of Pit 1 in 1981 (Spalding and Boegly, 1985).

Extractable metals are at background levels at this site.

Site 34. Below confluence of creeks of Sites 32 and 33. Site 34 is located below the confluence of the Site 32 and Site 33 creeks. Taken together, sites 32, 33, and 34 are intended to evaluate the upstream contribution measured at Site 6.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	174 \pm 68	770 \pm 110	148 \pm 70
	1985	205 \pm 100	320 \pm 30	135 \pm 35

This site taken together with the previous two sites is meant to characterize the upstream contribution of the creek east of SWSA 6. All three sites have less ^{90}Sr in 1985 than they had in 1978. This was also true of site 6 which is downstream of these localities. Thus it appears that this entire drainage is less contaminated with ^{90}Sr than it was in 1978. Future monitoring of this drainage should establish if this is the case. If so, it may represent a good

drainage to study the recovery of a small creek that has had the contamination source stopped or at least considerably lowered.

Extractable metals are at background levels at this site.

Site 35. Creek on east end of SWSA 6. Site 35 is located on a small creek on the east side of SWSA 6.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	23	<5
	1985	97	11	390

While ^{90}Sr has not increased from 1978 to 1985, ^{60}Co and ^{137}Cs values have increased considerably. This appears to be a new source of contamination in the basin.

Extractable Cu and Zn also appear to be well above background levels at this locality.

Site 36. Second creek on east end of SWSA 6. Site 36 is located on a small creek on the east side of SWSA 6. Sites 35 and 36 are meant to document the state of contamination of the east drainages in SWSA 6. The 1978 survey showed no evidence of contamination at that time.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	50	38
	1985	100	29	760

Sites 35 and 36 were to serve as checks on the contamination level of SWSA 6. These two creeks showed little contamination in 1978; however, they both showed increases in the level of ^{60}Co and ^{137}Cs . The source of this new contamination probably merits investigation.

Extractable metals are near background levels at this locality.

Site 37. Headwaters of western creek in SWSA 6. Site 37 is located at the fence boundary in SWSA 6 on the creek with Site 7. It was collected at the request of T. Tamura who suggested the possibility of active contamination in the north part of SWSA 6. This site had no evidence of contamination in the 1978 survey.

	year	^{60}Co (Beq/kg)	^{90}Sr (Beq/kg)	^{137}Cs (Beq/kg)
gravel:	1978	<5	21±5	7±5
	1985	7	290	7

This site was selected to serve as a check of the upstream contribution from SWSA 6. It appears that significant new contamination of ^{90}Sr occurs in SWSA 6 above Site 37.

Site 38. Stream Profile 1. Several additional samples were collected along the length of White Oak Creek south of the ORNL main complex. This was done to identify more closely the geographic location of discharge points attributed to the ORNL plant effluents. This profile supports the suggestion that the Process Waste Treatment discharge is the dominant source of radionuclide discharge from the ORNL complex.

Site 39. Stream Profile 2. A detailed profile of Melton Branch was completed. This was intended to duplicate the 1978 survey of Spalding and Cerling (1981, 1982) to study changes since that time in the radionuclide content of gravel. The intention was to see how the contaminant load had changed since the 1978 survey. Figures 6, 7, and 8 show the stream profiles for 1978 and for 1985 using three point running averages. It shows that the ^{60}Co contaminant levels of the stream bed is essentially unchanged; that ^{90}Sr is slightly lower in the headwaters but has essentially the same value downstream of the HFIR - NSPP confluence; and the ^{137}Cs is significantly lower in 1985 than in 1978 in the stretch south of SWSA 5.

RADIONUCLIDE DISCHARGE IN WHITE OAK CREEK BASIN: FLUX ESTIMATES

It has previously been suggested that flux is more important than absolute concentration in discussions of contaminant discharge. Previously, Cerling and Spalding (1981, 1982) used distribution coefficients and drainage basin area to estimate the relative discharge of radionuclides in White Oak Creek watershed. In the present study enough discharge data is present to make absolute discharge estimates in the watershed. Several problems should be kept in mind when considering the estimates below. First, while most flow measurements are probably correct to $\pm 20\%$, some discharge estimates must be made on the basis of the subtraction of two large numbers. In such cases flow estimates may be in considerable variance. Second, the flow values used in the present estimates are from 15 July 1985 to 15 August 1985 and are applicable only to that time. Third, only the distribution coefficient for ^{90}Sr is for a reversible reaction. The distribution coefficients for ^{60}Co and for ^{137}Cs are empirical and are discussed below.

Distribution coefficients were measured for ^{90}Sr and for ^{137}Cs using standard methods (see Cerling and Spalding, 1981) on gravel used in the SORB experiments and on gravel samples for sites 1 through 17. In addition Cerling and Spalding (1981) also measured distribution coefficients for ^{60}Co , ^{90}Sr , and ^{137}Cs for samples throughout the basin. Only the ^{90}Sr values will be used in the present discussion. These are presented in Table 6 along with data on the composition of gravel from each locality. ^{60}Co and ^{137}Cs "distribution coefficients" are not reversible and thus cannot be treated as distribution coefficients and will here be called "adsorption coefficients" because it has been observed in a previous study that continuous adsorption ^{60}Co and ^{137}Cs occurs (Cerling and Turner, 1982); these will be referred to as K^* which is determined empirically. Daily concentrations of ^{60}Co and ^{137}Cs at Site 1 are known from samples collected by the Manning pumps for the period 31 July to 15 August. In this case we will assume that the period 15 July to 30 July had a similar

history. The final SORB concentration for ^{60}Co and ^{137}Cs is then divided by the average water composition divided by the number of days for adsorption giving units of $\text{ml-gm}^{-1}\text{-d}^{-1}$. For ^{60}Co and ^{137}Cs at Site 1 this gives K^* values of $6.9 \times 10^3 \text{ ml-gm}^{-1}\text{-d}^{-1}$ and $9.4 \times 10^4 \text{ ml-gm}^{-1}\text{-d}^{-1}$. The K_d value used for ^{90}Sr is 81 ml-gm^{-1} . Table 7 shows the estimated fluxes for radionuclides in White Oak Creek watershed for the period 15 July 1985 to 15 August 1985.

^{60}Co Flux. For ^{60}Co , clearly the most important source in the basin identified in this study is the HFIR discharge. Two points are well established downstream from HFIR: Monitoring Station 4A which gives an estimated flux of 25 mCi and Monitoring Station 4 which gives an estimated flux of 2.6 mCi indicating that a major portion of the ^{60}Co was adsorbed to sediments in this interval. This would imply that the HFIR discharge was significantly higher than 25 mCi for the study period. Extrapolation back to the source would yield an estimated flux of more than 100 mCi per month. The second most important source is the Process Waste Treatment Plant with a discharge of about 10 mCi ^{60}Co for the study period.

It is important to estimate of the ^{60}Co discharge from Trench 7 which has been identified as having highly contaminated seepage waters (1000 to 2000 Beq L^{-1} ; Means, et al., 1978; Olson, et al., 1986). Making a few assumptions it is possible to make a reasonable estimate of the importance of this site to the overall ^{60}Co discharge. If this seep has a concentration of 1000 Beq-L^{-1} it must have a flow of $3.7 \times 10^6 \text{ L-mo}^{-1}$ to have a flux comparable to that from the HFIR source:

$$100 \text{ mCi-mo}^{-1} = 1000 \text{ Beq-L}^{-1} \times \text{Ci-} 3.7 \times 10^{10} \text{ Beq}^{-1} \times 1000 \text{ mCi-Ci}^{-1} \times 3.7 \times 10^6 \text{ L-mo}^{-1}$$

This represents a much higher flow than can be expected from this seep. Comparison with values in Table 7 show that such a flow is much greater than the gauged stream in SWSA 6

for this period. Thus it is likely that the ^{60}Co flux from Trench 7 is considerably less than that from HFIR or from the main ORNL plant complex.

In this discussion it is important to recognize the preliminary nature of the use of K^* for these calculations.

^{90}Sr flux. Table 7 shows that the most significant source of ^{90}Sr in the basin is from the main ORNL plant complex, probably from the Process Waste Treatment Plant with an estimated discharge of at least 40 mCi for the period of study. Other sources include the Northwest Tributary (7.6 mCi) having a ^{90}Sr seep in the main channel and receiving discharge from First Creek; SWSA 5 (5.7 mCi); HRT settling basin (3.5 mCi); SWSA 4 (1.6 mCi); SWSA 6 (0.5 mCi); and a source upstream from Monitoring Station 2 (3.5 mCi). Clearly the most significant source during this study period was the main ORNL plant complex, most likely the Process Waste Treatment Plant.

^{137}Cs flux. Only three localities show evidence for ^{137}Cs flux exceeding 0.1 mCi for the study period. All of these are downstream from the main ORNL plant complex and the Process Waste Treatment Plant discharge. Use of K^* indicates that the ^{137}Cs flux for this period was about 120 mCi, all of which is most likely from the Process Waste Treatment Plant.

METALS IN WHITE OAK CREEK BASIN SEDIMENTS

Table 5 and Figures 9 through 23 show the extractable metal contents for Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, P, V, and Zn. Several other metals were analyzed as well, but they showed little variation within the basin. These include Ag, As, B, Ga, K, Li, Na, Pb, Se, and Sr. The distribution of each of these metals will be discussed in turn.

Aluminum. Extractable aluminum has only slight variation in the entire watershed. The lowest values are in Bethel valley which has the lowest shale content.

Arsenic. Extractable arsenic was less than the detection limit (6 ppm) for all samples.

Barium. Barium varies little throughout the basin. In fact, one of the background sites (Site 17) is among the highest in extractable barium.

Boron. Extractable boron was less than 5 ppm for all samples.

Calcium. Calcium was mapped to show the dependance on carbonate values. Samples with the highest carbonate values (Appendix 2) also have the highest extractable calcium. Most of these samples are in Bethel Valley. Interestingly, one sample outside of Bethel Valley with high extractable calcium (Site 5) has about 30% carbonate fragments. This may be a result from gravel associated with the roads in the area which have a limestone base.

Cadmium. Only a few samples have higher than background cadmium values: all of these are in White Oak Creek or the Northwest Tributary. However, the known association of cadmium with calcium carbonate suggests that this may be an artifact of sampling bias created by differing bedrock compositions.

Cobalt. There is no definite pattern to the distribution of cobalt in the basin. One of the highest observed values is from the locality chosen for a representative background sample. Cobalt does not appear to be correlated with the amount of manganese coating on the sediments.

Chromium. Background chromium levels seem to be about 1 or 2 ppm. All samples with values significantly higher than this (>10 ppm) are associated with known Zn contamination: ORNL lab complex and HFIR which attain average values as high as 16 ppm. As with Zn, the Cr contamination in the ORNL laboratory complex may be associated with the cooling effluent south of Building 4500S. In addition, there is a suggestion of chromium input by the NSPP and MSRE areas. There is no evidence for chromium input from any of the SWSA areas.

Copper. Background values for copper appear to be about 0.5 ppm. As with chromium, the known areas of Zn contamination (ORNL lab complex and HFIR) show the highest copper values (up to 9 ppm) which are more than 10 times the background value. The only significant Cu value associated with the SWSA region is from SWSA 6 on the east side. This should be examined further since this area showed evidence for ^{60}Co and ^{137}Cs contamination, as well.

Iron. Iron is ubiquitous in the near surface environment. It is leached from sediments in slightly reducing conditions and precipitated in oxidizing portions of streams (Cerling and Turner, 1982). Variations in iron are most likely related to the interaction between groundwater input (high Fe content) into streams, and the relative stream velocity which can abrade Fe/Mn coatings.

Gallium. Extractable gallium was less than 3 ppm for all samples.

Lead. All samples have extractable lead contents lower than 12 ppm.

Lithium. Extractable lithium was less than 15 ppm for all samples.

Magnesium. Magnesium values are similar throughout much of the basin, the one exception being Site 5. The reason for this is not clear. However, magnesium is not a toxic metal.

Manganese. The distribution of manganese in the basin varies only slightly. Like iron it is mobilized in slightly reducing conditions (such as groundwater) and is readily fixed in

oxidizing portions of streams. The extractant chosen is an excellent extractant for manganese and should extract those metals associated with Fe/Mn coatings.

Molybdenum. Background molybdenum values are about 0.5 ppm. The values significantly above background appear to be associated with the ORNL lab complex and HFIR. In addition, SWSA 4 appears to have high Mo values (7 ppm).

Nickel. Background nickel values seem to be about 5 ppm. Only one site has significantly higher values than background. This is SWSA 4 which has average values at least 50 times the background value.

Phosphorus. It was previously pointed out that phosphorus was an active input to the White Oak Creek system by the ORNL lab complex and by HFIR. Observations of extractable phosphorus from indigenous gravel confirms this previous observation.

Potassium. Extractable potassium ranged from 20 to 200 ppm.

Selenium. The detection limit for extractable selenium was 2 ppm. All samples had less than 3 ppm extractable selenium.

Silver. Extractable silver was less than the detection limit (0.5 ppm) for all samples.

Sodium. Extractable sodium ranges from 10 to 840 ppm.

Strontium. Extractable Sr ranged from 2 to 30 ppm.

Vanadium. No discernable differences in vanadium distribution are observed in the White Oak Creek Basin.

Zinc. The previous report showed that zinc was actively supplied into the White Oak Creek system. Background values are about 5 ppm and values 30 to 70 times this are associated with the ORNL lab complex and HFIR.

In summary, this study suggests that significant Cr, Cu, Mo, P, and Zn are being discharged into White Oak Creek and these metals are being adsorbed onto the sediments. In particular, extractable zinc levels in the sediments can reach about 100 times the background level. The principle points of discharge appear to be the ORNL laboratory

complex and HFIR, with minor discharge from the NSPP and MSRE areas. In addition, there appears to be significant Mo and Ni discharge from SWSA 4.

ORGANIC COMPOUNDS IN WHITE OAK CREEK BASIN SEDIMENTS.

Thirteen gravel samples and fourteen samples of organic rich ooze were collected to study the potential for contamination by organic compounds. Organic compounds were extracted according to Method 3540 (Environmental Protection Agency, 1984). The organic compounds tested for are listed in Table 8.

Of the gravel samples, all were below detection limits for all compounds except for four samples. Samples 5456, 5472, 5477, and 5481 (Sites 10, 12, 13, and 9A) tested positively for di-n-butyl phthalate and ranged from 20 to 30 ppm (detection limit of 10 ppm). In addition, sample 5472 (Site 12, at the effluent from the Waste Process Treatment Plant) had above detection limits (>10 ppm) for bis(2-ethylhexyl)phthalate (77ppm), fluoranthene (72 ppm), chrysene (55 ppm), anthracene (42 ppm), phenanthrene (100 ppm), and pyrene (56 ppm).

Of the samples of organic rich ooze, only three samples tested positively (>10 ppm) for the chosen organic compounds. Sample 5449 (Site 1) had values of 98, 89, and 28 ppm for bis(2-ethylhexyl)phthalate, benzyl butyl phthalate, and di-n-butyl phthalate, respectively. Sample 5457 (Site 10) had values of 113, 97, and 18 ppm for bis(2-ethylhexyl)phthalate, benzyl butyl phthalate, and di-n-butyl phthalate, respectively. Sample 5473 (Site 12) had values of 43 and 92 ppm for benzo(a)pyrene and benzo(b)fluoranthene respectively.

In summary, little organic contamination seems to be present in the basin.

CHANGES IN STREAM WATER CHEMISTRY IN THE BASIN.

Samples of stream water were collected from the primary sampling sites (Sites 1 - 17) on 13 August, 1985 (Figure 2). Samples 5661 through 5664 were collected in the morning of 13 August, samples 5665 to 5674 and 5681 were collected in the afternoon of 13 August. Alkalinity was measured within 4 hours after collection for each of the samples; cations were analyzed by atomic absorption, anions by ion chromatography, and silica by ICP. Analyses from these sites are presented in Table 9.

Background samples. It is useful to discuss water samples that represent a minimum of anthropogenic input. Two such samples are 5661 and 5681. Sample 5661 was collected at Site 10 (Figure 2) near the headwaters of White Oak Creek and is representative of waters derived primarily from the Knox dolomite. Significantly, it is a water dominated by Ca-Mg-HCO₃: the Ca:Mg ratio approaches 1 which would be expected in a water derived from the weathering of dolomite. Sample 5681 (Site 17) predominantly drains the Conasauga Shale in upper Melton Branch. It is a water dominated by Ca-HCO₃: much less magnesium is present because comparatively little dolomite is present in the drainage basin. Because of extensive weathering of the shale, this water appears to be primarily a result of dissolution of carbonates that are present in the Conasauga Shale. The important characteristics of both of these waters is that $m(\text{Ca}^{+2}) + m(\text{Mg}^{+2}) \gg m(\text{Na}^{+}) + m(\text{K}^{+})$, $m(\text{HCO}_3^{-}) \gg m(\text{Cl}^{-}) + m(\text{SO}_4^{-2})$, and $m(\text{NO}_3^{-}) < 0.1$ mmole per liter (in the ensuing discussion, charges will be omitted from the ions). While no water samples were collected from an undisturbed part of the basin draining only Chicamauga limestone it is likely that it has a water composition similar to sample 5681 which is controlled by limestone dissolution. Sample 5674 taken at the staff gauge in Northwest Tributary may have a composition similar to the background; however because it is downstream of plant effluents it is likely to be at least slightly contaminated. The higher chloride values suggest this as well.

Comparison of other water samples suggests that only sample 5671 from SWSA 6 has a chemistry that is comparable to the background values. All other samples have a chemistry that is significantly different, usually higher in Na, alkalinity, Cl, SO_4 , and NO_3 .

Anthropogenically affected samples. There are several approaches to understanding the changes in chemistry of waters resulting from anthropogenic activities. Diagrammatically, these can be shown in several ways. These include triangular diagrams to illustrate the changes in the proportions of dissolved species; this shows the relative importance of dissolved species for mineral reactions. The first of these is to plot SiO_2 , alkalinity, and $\text{SO}_4 + \text{Cl}$ at the three apexes. Figure 24 shows that there is an important increase in the relative amounts of $\text{SO}_4 + \text{Cl}$ for many of the waters in the basin. Examination of the anions in more detail can be accomplished by examination of a diagram with SO_4 , Cl, and NO_3 at the apexes. In spite of the real increase in SO_4 and Cl, this diagram (Figure 25) shows an important increase in the amount of NO_3 in the waters. This is not accompanied by a noticeable increase in PO_4 . Examination of cation ratios show that the effect of the ORNL activities is to greatly increase the proportions of Na with respect to Ca and Mg (Figure 26). Lastly, one can compare each of the ions in White Oak Creek at Monitoring Station 3 (5668) to the headwater sample (5661); and that in Melton Branch at Monitoring Station 4 (5667) to the headwater sample (5681). Figure 27 shows that Na, alkalinity, SO_4 , Cl, and NO_3 show major increases as a result of ORNL activities, and suggest that the anthropogenic component for each of these is on the order of 90%, 80%, 90%, and 90% respectively. This suggests that ORNL activities have greatly altered stream chemistry. Such a finding is similar to that for the Rhine River (Stumm and Morgan, 1981).

Another interesting observation of this study concerns the downstream change in chemistry between the sample taken at the Third Street Bridge (5662) and that taken at Monitoring Station 2A (5673). The former sample was taken in the morning about 1100 hours, while the latter was collected at about 1530 hours. The drastic change in chemistry

between these two samples may result from differing plant effluent releases in the afternoon compared to those in the morning.

SUMMARY

This survey shows that gravels can be effectively used to understand the nature of contamination in watersheds. The use of a tethered substrate can demonstrate if certain localities are the sites of active contamination. This works for radionuclides as well as for various metals. In addition, the re-survey of localities can show if conditions have improved in the intervening time period.

While still preliminary, this survey implies that the most important source of ^{60}Co contamination is the HFIR facility, the most important source of ^{90}Sr contamination is the ORNL facility, and the most important source of ^{137}Cs contamination is ORNL facility. Several localities show probable improvements in conditions from 1978 to the present: these are the creek east of SWSA 5; the creek leading to Pits 1, 2, and 3; the creek leading to Trenches 4, 5, and 6; and the creek on the west side of SWSA 6. The creeks on the east side of SWSA 6 and First Creek appear to have become more contaminated in the intervening interval.

The metal contribution of ORNL is measureable for the metals Cr, Cu, Mo, Ni, P, and Zn. This is typical of industrial outputs (Salomons and Forstner, 1984) although the levels should probably be further quantified. This survey implies that the cooling facilities at 4500S and at HFIR make important contributions of Zn and P and minor contributions of Cr, Cu and Mo to the watershed. There appears to be a contribution of Ni originating in SWSA 4. In addition, the chemistry of White Oak Creek and Melton Branch are significantly changed by the activities of ORNL. The sodium, chloride, sulfate, and nitrate fluxes are considerably enhanced. This is typical of anthropogenic changes to rivers in any region and is probably not of a significant nature.

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**APPENDIX I. SAMPLES COLLECTED FOR STREAM CHARACTERIZATION
SURVEY.**

ID	SITE	DATE	TYPE	LOC	78 SURV	NORTH	EAST
5401	17	07/19/85	GRAV	SWSA7	.	16000	33360
5402	2	07/19/85	SORB	MS4	D156	16875	28310
5403	2	07/19/85	CLAM	MS4	D156	16875	28310
5404	14	07/19/85	CLAM	MS2A	D39	19845	29520
5405	10	07/19/85	CLAM	JKL	.	24120	37980
5406	14	07/19/85	SORB	MS2A	D40	19750	29470
5407	9B	07/19/85	SORB	SWSA4	D108	18675	28780
5408	1	07/19/85	SORB	MS3	D68	17200	28045
5409	1	07/19/85	GLASS	MS3	D68	17200	28045
5410	2	07/19/85	SORB	MS4	D158	16865	28085
5411	2	07/19/85	GLASS	MS4	D158	16865	28085
5412	3	07/19/85	SORB	MS4A	D129	16675	31125
5413	4	07/19/85	SORB	MS4B	D197	17720	30935
5414	4	07/19/85	GLASS	MS4B	D197	17720	30935
5415	16	07/19/85	SORB	HFIR	D177	16315	32555
5416	16	07/19/85	SORB	HFIR	D177	16315	32555
5417	15	07/19/85	SORB	HFIR	D172	16650	32835
5418	17	07/19/85	SORB	SWSA7	.	16000	33360
5419	5	07/19/85	SORB	T345	D305	16875	26265
5420	6	07/19/85	SORB	SWSA6E	D241	16920	25340
5421	10	07/19/85	SORB	JKL	.	24120	37980
5422	10	07/19/85	GLASS	JKL	.	24120	37980
5423	11	07/19/85	SORB	COOL	.	21360	32450
5424	13	07/19/85	SORB	NWT	D292	20630	29640
5425	8	07/23/85	SORB	MS2	D12	21165	31365
5426	8	07/23/85	GRAV	MS2	D12	21165	31365
5427	12	07/23/85	SORB	3RDST	D21	21140	30710
5428	12	07/23/85	GRAV	3RDST	D21	21140	30710
5429	9A	07/23/85	GRAV	SWSA4	D103	18890	28300
5430	9A	07/24/85	SORB	SWSA4	D103	18890	28300
5431	9A	07/24/85	GLASS	SWSA4	D103	18890	28300
5432	1	07/24/85	GRAV	MS3	D68	17200	28045
5433	38	07/24/85	GRAV	WOC	D70	17090	27880
5434	10	07/24/85	GRAV	JKL	.	24120	37980
5435	11	07/24/85	GRAV	COOL	.	21360	32450
5436	7	07/24/85	SORB	SWSA6	D350	16050	23890
5437	7	07/24/85	GRAV	SWSA6	D350	16050	23890
5438	37	07/24/85	GRAV	MISC	D341	17020	24100
5439	6	07/25/85	GRAV	SWSA6E	D241	16920	25340
5440	5	07/25/85	GRAV	T345	D305	16875	26265
5441	2	07/25/85	GRAV	MS4	D158	16865	28085
5442	2	07/25/85	GRAV	MS4	D159	16895	27990
5443	16	07/25/85	GRAV	HFIR	D177	16315	32555
5444	15	07/25/85	GRAV	HFIR	D172	16650	32835
5445	3	07/25/85	GRAV	MS4A	D130	16705	31020
5446	4	07/25/85	GRAV	MS4B	D196	17805	31010
5447	13	07/25/85	GRAV	NWT	D292	20630	29640
5448	1	07/26/85	ORG	MS3	D68	17200	28045
5449	1	07/26/85	OOZE	MS3	D67	17320	28080
5450	1	07/26/85	WFIL	MS3	D67	17320	28080

5451	10	07/29/85	GRAV JKL	.	24120	37980
5452	10	07/29/85	GRAV JKL	.	24120	37980
5455	10	07/29/85	GRAV JKL	.	24120	37980
5456	10	07/29/85	ORG JKL	.	24120	37980
5457	10	07/29/85	OOZE JKL	.	24120	37980
5458	10	07/29/85	JCO-1 J	.	24120	37980
5459	10	07/29/85	JCO-2 J	.	24120	37980
5460	10	07/29/85	JCS-1 J	.	24120	37980
5461	10	07/29/85	JCS-2 J	.	24120	37980
5462	10	07/29/85	JSR-1 J	.	24120	37980
5463	10	07/29/85	JSR-2 J	.	24120	37980
5464	10	07/29/85	PLATE K	.	24120	37980
5465	11	07/29/85	ORG COOL	.	21360	32450
5466	11	07/29/85	GRAV COOL	.	21360	32450
5468	11	07/29/85	OOZE COOL	.	21360	32450
5469	11	07/29/85	GRAV COOL	.	21360	32450
5470	38	07/29/85	GRAV 5THST	.	21370	31790
5471	38	07/29/85	GRAV WOC	.	21440	31610
5472	12	07/29/85	ORG 3RDST	D21	21140	30710
5473	12	07/29/85	OOZE 3RDST	D21	21140	30710
5474	38	07/29/85	GRAV .	D25	21035	30345
5475	13	07/29/85	GRAV NWT	D292	20630	29640
5476	13	07/29/85	GRAV NWT	D293	20575	29680
5477	13	07/29/85	ORG NWT	D292	20630	29640
5478	13	07/29/85	OOZE NWT	D292	20630	29640
5479	14	07/29/85	OOZE MS2A	D40	19750	29470
5480	9A	07/30/85	OOZE SWSA4	D103	18890	28300
5481	9A	07/30/85	ORG SWSA4	D103	18890	28300
5482	9A	07/30/85	GRAV SWSA4	D103	18890	28300
5483	9A	07/30/85	GRAV SWSA4	D103	18890	28300
5484	9A	07/30/85	WFIL SWSA4	D103	18890	28300
5485	9A	07/30/85	WFIL SWSA4	D103	18890	28300
5486	9A	07/30/85	FILT SWSA4	D103	18890	28300
5487	9A	07/30/85	PLATE SWSA4	D103	18890	28300
5488	1	07/31/85	GRAV MS3	D68	17200	28045
5489	1	07/31/85	GRAV MS3	D68	17200	28045
5490	2	07/31/85	GRAV MS4	D160	17000	27950
5491	1	08/01/85	WSUS MS3	D68	17200	28045
5492	2	08/01/85	WSUS MS4	D158	16865	28085
5493	2	08/01/85	ORG MS4	D158	16865	28085
5494	2	08/01/85	OOZE MS4	D157	16895	28195
5495	5	08/01/85	WFIL T345	D305	16875	26265
5496	5	08/01/85	GRAV T345	D305	16875	26265
5497	5	08/01/85	GRAV T345	D305	16875	26265
5498	5	08/01/85	ORG T345	D305	16875	26265
5499	5	08/01/85	OOZE T345	D305	16875	26265
5500	6	08/01/85	GRAV SWSA6E	D241	16920	25340
5501	6	08/01/85	GRAV SWSA6E	D241	16920	25340
5502	6	08/01/85	ORG SWSA6E	D241	16920	25340
5503	6	08/01/85	OOZE SWSA6E	D241	16920	25340

5504	6	08/01/85	WFIL	SWSA6E	D241	16920	25340
5505	7	08/01/85	GRAV	SWSA6	D353	16340	24975
5506	7	08/01/85	GRAV	SWSA6	D359	16300	24925
5507	7	08/01/85	WFIL	SWSA6	D350	16050	23990
5508	7	08/01/85	GRAV	SWSA6	D350	16050	23990
5509	7	08/01/85	GRAV	SWSA6	D350	16050	23990
5510	7	08/01/85	ORG	SWSA6	D350	16050	23990
5511	7	08/01/85	DOZE	SWSA6	D350	16050	23990
5512	3	08/02/85	WFIL	MS4A	D129	16675	31125
5513	3	08/02/85	ORG	MS4A	D129	16675	31125
5514	3	08/02/85	DOZE	MS4A	D128	16570	31295
5515	27	08/02/85	GRAV	F	D202	17220	30680
5516	27	08/02/85	GRAV	F	D202	17220	30680
5517	27	08/02/85	GRAV	F	D202	17220	30680
5518	27	08/02/85	PLATE	F	D202	17220	30680
5519	1	08/02/85	WSUS	MS3	D68	17200	29045
5520	2	08/02/85	WSUS	MS4	D158	16865	28085
5521	24	08/02/85	GRAV	MSRE	D186	18495	31755
5522	24	08/02/85	GRAV	MSRE	D186	18495	31755
5523	24	08/02/85	GRAV	MSRE	D186	18495	31755
5524	25	08/02/85	GRAV	HRT	D189	18415	31450
5525	25	08/02/85	GRAV	HRT	D189	18415	31450
5526	25	08/02/85	GRAV	HRT	D189	18415	31450
5527	26	08/02/85	GRAV	NSPP	D182	18680	31625
5528	26	08/02/85	GRAV	NSPP	D182	18680	31625
5529	26	08/02/85	GRAV	NSPP	D182	18680	31625
5530	4	08/02/85	WFIL	MS4B	D197	17720	30935
5531	4	08/02/85	ORG	MS4B	D197	17720	30935
5532	4	08/02/85	DOZE	MS4B	D197	17720	30935
5533	33	08/05/85	GRAV	P123	D226	18170	25640
5534	33	08/05/85	GRAV	P123	D226	18170	25640
5535	33	08/05/85	GRAV	P123	D226	18170	25640
5536	32	08/05/85	GRAV	P123	D230	17945	25710
5537	32	08/05/85	GRAV	P123	D230	17945	25710
5538	32	08/05/85	GRAV	P123	D230	17945	25710
5539	34	08/05/85	GRAV	P123	D231	17930	25565
5540	34	08/05/85	GRAV	P123	D231	17930	25565
5541	34	08/05/85	GRAV	P123	D231	17930	25565
5542	32	08/05/85	GRAV	P123	D230	17945	25710
5543	34	08/05/85	GRAV	P123	D231	17930	25565
5544	34	08/05/85	GRAV	P123	D231	17930	25565
5545	30	08/05/85	GRAV	T567	D320	16975	27180
5546	.	08/05/85	.	T567	.	.	.
5547	31	08/05/85	GRAV	T567	D325	17100	27175
5548	31	08/05/85	GRAV	WOC	D78	16830	27090
5549	31	08/05/85	GRAV	WOC	D78	16830	27090
5550	31	08/05/85	GRAV	WOC	D79	16780	26990
5551	1	08/05/85	WFIL	MS3	D66	17475	28195
5552	1	08/05/85	WSUS	MS3	D66	17475	28195
5553	2	08/05/85	WSUS	MS4	D158	16865	28085

5554	1	08/05/85	GRAV MS3	D68	17200	28045
5555	2	08/05/85	GRAV MS4	D160	17000	27950
5556	18	08/05/85	GRAV 1STCRK	D404	21630	29625
5557	18	08/05/85	GRAV 1STCRK	D404	21630	29625
5558	19	08/05/85	GRAV 1STCRK	D407	22090	29620
5559	9A	08/05/85	WFIL SWSA4	D103	18890	28300
5560	9A	08/05/85	FILT SWSA4	D103	18890	28300
5561	9A	08/05/85	GRAV SWSA4	D103	18890	28300
5562	9A	08/05/85	GRAV SWSA4	D103	18890	28300
5563	4	08/06/85	WFIL MS4B	D197	17720	30935
5564	1	08/06/85	WSUS MS3	D68	17200	28045
5565	2	08/06/85	WSUS MS4	D160	17000	27950
5566	1	08/07/85	WSUS MS3	D68	17200	28045
5567	2	08/07/85	WSUS MS4	D160	17000	27950
5568	29	08/08/85	GRAV T7	D244	17295	27840
5569	29	08/08/85	GRAV T7	D244	17295	27840
5570	29	08/08/85	ORG T7	D244	17295	27840
5571	29	08/08/85	OOZE T7	D244	17295	27840
5572	39	08/08/85	GRAV MB	D163	17075	33030
5573	39	08/08/85	GRAV MB	D162	17150	32995
5574	39	08/08/85	GRAV MB	D161	17250	32975
5575	39	08/08/85	GRAV MB	D165	17240	33210
5576	39	08/08/85	GRAV MB	D164	17130	33155
5577	39	08/08/85	GRAV MB	D167	17025	33075
5578	39	08/08/85	GRAV MB	D168	16960	33065
5579	39	08/08/85	GRAV MB	D170	16785	32015
5580	39	08/08/85	GRAV MB	D172	16650	32035
5581	39	08/08/85	GRAV MB	D175	16440	32755
5582	39	08/08/85	GRAV MB	D176	16395	32650
5583	16	08/08/85	GRAV G	D177	16315	32555
5584	16	08/08/85	GRAV G	D177	16315	32555
5585	22	08/08/85	GRAV MB	D115	16290	32590
5586	22	08/08/85	GRAV MB	D114	16230	32690
5587	17	08/08/85	GRAV MB			
5588	1	08/08/85	WSUS MS3	D68	17200	28045
5589	2	08/08/85	WSUS MS4	D160	17000	27950
5590	3	08/08/85	WFIL MS4A	D129	16675	31125
5591	3	08/08/85	FILT MS4A	D129	16675	31125
5592	3	08/08/85	WSUS MS4A	D129	16675	31125
5593	22	08/08/85	WFIL MB	D115	16290	32590
5594	23	08/08/85	FILT MB	D115	16280	32590
5595	23	08/08/85	GRAV MB	D116	16305	32465
5596	23	08/08/85	GRAV MB	D116	16305	32485
5597	23	08/08/85	GRAV MB	D117	16280	32380
5598	39	08/08/85	GRAV MB	D118	16245	32270
5599	39	08/08/85	GRAV MB	D119	16285	32160
5600	39	08/08/85	GRAV MB	D120	16200	32045
5601	39	08/08/85	GRAV MB	D120	16200	32045
5602	39	08/08/85	GRAV MB	D121	16280	31965
5603	39	08/08/85	GRAV MB	D122	16270	31870

5604	39	08/08/85	GRAV MB	D122	16270	31870
5605	39	08/09/85	GRAV MB	D123	16270	31760
5606	39	08/09/85	GRAV MB	D124	16315	31660
5607	39	08/09/85	GRAV MB	D125	16360	31560
5608	39	08/09/85	GRAV MB	D126	16415	31465
5609	39	08/09/85	GRAV MB	D127	16480	31355
5610	39	08/09/85	GRAV MB	D127	16480	31355
5611	3	08/09/85	GRAV MB	D129	16675	31125
5612	3	08/09/85	GRAV MB	D130	16705	31020
5613	39	08/09/85	GRAV MB	D131	16795	30965
5614	39	08/09/85	GRAV MB	D132	16780	30860
5615	39	08/09/85	GRAV MB	D134	16815	30635
5616	39	08/09/85	GRAV MB	D134	16815	30635
5617	39	08/09/85	GRAV MB	D135	16815	30515
5618	39	08/09/85	GRAV MB	D136	16800	30410
5619	39	08/09/85	GRAV MB	D137	16800	30300
5620	39	08/09/85	GRAV MB	D138	16775	30185
5621	39	08/09/85	GRAV MB	D139	16765	30075
5622	39	08/09/85	GRAV MB	D140	16735	29970
5623	39	08/09/85	GRAV MB	D140	16725	29970
5624	1	08/09/85	WFIL MS3	D68	17200	28045
5625	1	08/09/85	FILT MS3	D68	17200	28045
5626	1	08/09/85	WSUS MS3	D68	17200	28045
5627	1	08/09/85	WSUS MS3	D68	17200	28045
5628	2	08/09/85	WSUS MS4	D160	17000	27950
5629	39	08/09/85	GRAV MB	D141	16700	29955
5630	39	08/09/85	GRAV MB	D142	16680	29745
5631	39	08/09/85	GRAV MB	D143	16730	29630
5632	39	08/09/85	GRAV MB	D144	16775	29575
5633	39	08/09/85	GRAV MB	D145	16845	29510
5634	39	08/09/85	GRAV MB	D145	16845	29510
5635	39	08/09/85	GRAV MB	D146	16910	29415
5636	39	08/09/85	GRAV MB	D147	16920	29310
5637	39	08/09/85	GRAV MB	D147	16920	29310
5638	39	08/09/85	GRAV MB	D148	16930	29205
5639	39	08/09/85	GRAV MB	D148	16925	29095
5640	39	08/09/85	GRAV MB	D150	16970	28980
5641	39	08/09/85	GRAV MB	D151	16845	28870
5642	39	08/09/85	GRAV MB	D152	16875	28750
5643	39	08/09/85	GRAV MB	D153	16900	28645
5644	39	08/09/85	GRAV MB	D153	16900	28645
5645	39	08/09/85	GRAV MB	D154	16875	28540
5646	39	08/09/85	GRAV MB	D154	16875	28540
5647	1	08/12/85	WFIL MS3	D68	17200	28045
5648	1	08/12/85	FILT MS3	D68	17200	28045
5649	1	08/12/85	WSUS MS3	D68	17200	28045
5650	1	08/12/85	WSUS MS3	D68	17200	28045
5651	2	08/12/85	WFIL MS4	D160	17000	27950
5652	2	08/12/85	FILT MS4	D160	17000	27950
5653	2	08/12/85	WSUS MS4	D160	17000	27950

5654	2	08/12/85	WSUS MS4	D160	17000	27950
5655	5	08/12/85	WFIL T345	D305	16875	26265
5656	5	08/12/85	FILT T345	D305	16875	26265
5657	6	08/12/85	WFIL SWSAGE	D241	16920	25340
5658	6	08/12/85	FILT SWSAGE	D241	16920	25340
5659	7	08/12/85	WFIL SWSA6	D350	16050	23890
5660	7	08/12/85	FILT SWSA6	D350	16050	23890
5661	10	08/13/85	WSUS J	.	24120	37980
5662	12	08/13/85	WSUS 3RDST	.	21170	30740
5663	8	08/13/85	WSUS MS2	D12	21165	31365
5664	11	08/13/85	WSUS COOL	.	21360	32450
5665	4	08/13/85	WSUS MS4B	D197	17720	30935
5666	3	08/13/85	WSUS MS4A	D129	16675	31125
5667	2	08/13/85	WSUS MS4	D160	17000	27950
5668	1	08/13/85	WSUS MS3	D68	17200	28045
5669	5	08/13/85	WSUS T345	D305	16875	26265
5670	6	08/13/85	WSUS SWSAGE	D241	16920	25340
5671	7	08/13/85	WSUS SWSA6	D350	16050	23890
5672	9A	08/13/85	WSUS SWSA4	D103	18890	28300
5673	14	08/13/85	WSUS MS2A	D40	19750	29470
5674	13	08/13/85	WSUS NWT	D292	20630	29640
5675	1	08/13/85	WSUS MS3	D68	17200	28045
5676	2	08/13/85	WSUS MS4	D160	17000	27950
5677	3	08/13/85	WFIL MS4A	D129	16675	31125
5678	3	08/13/85	FILT MS4A	D129	16675	31125
5679	4	08/13/85	WFIL MS4B	D197	17720	30935
5680	22	08/13/85	WFIL MB	D115	16280	32590
5681	22	08/13/85	WSUS MB	D115	16280	32590
5682	10	08/14/85	WFIL J	.	24120	37980
5683	10	08/14/85	GLASS J	.	24120	37980
5684	10	08/14/85	SORB J	.	24120	37980
5685	10	08/14/85	PLATE J	.	24120	37980
5686	10	08/14/85	PLATE J	.	24120	37980
5687	10	08/14/85	FILT J	.	24120	37980
5688	11	08/14/85	SORB COOL	.	21360	32450
5689	8	08/14/85	SORB MS2	D12	21165	31365
5690	12	08/14/85	SORB 3RDST	.	21170	30740
5691	13	08/14/85	SORB NWT	D292	20630	29640
5692	14	08/14/85	SORB MS2A	D40	19750	29470
5693	9B	08/14/85	SORB SWSA4	D103	18890	28300
5694	9A	08/14/85	WFIL SWSA4	D103	18890	28300
5695	9A	08/14/85	FILT SWSA4	D103	18890	28300
5696	9A	08/14/85	GLASS SWSA4	D103	18890	28300
5697	9A	08/14/85	SORB SWSA4	D103	18890	28300
5698	9A	08/14/85	PLATE SWSA4	D103	18890	28300
5699	7	08/14/85	SORB SWSA6	D350	16050	23890
5700	6	08/14/85	SORB SWSAGE	D241	16920	25340
5701	6	08/14/85	MISC SWSAGE	D241	16920	25340
5702	6	08/14/85	PLATE SWSAGE	D241	16920	25340
5703	5	08/14/85	SORB T345	D305	16875	26265

5704	1	08/14/85	WSUS MS3	D68	17200	28045
5705	2	08/14/85	WSUS MS4	D160	17000	27950
5706	20	08/15/85	WFIL NWT	D271	21900	27810
5707	20	08/15/85	FILT NWT	D271	21900	27810
5708	20	08/15/85	GRAV NWT	D271	21900	27810
5709	20	08/15/85	GRAV NWT	D269	22000	27560
5710	21	08/15/85	GRAV NWT	D278	21650	28485
5711	4	08/15/85	WFIL MS4B	D197	17720	30935
5712	4	08/15/85	FILT MS4B	D197	17720	30935
5713	4	08/15/85	SORB MS4B	D197	17720	30935
5714	4	08/15/85	GLASS MS4B	D197	17720	30935
5715	4	08/15/85	PLATE MS4B	D197	17720	30935
5716	27	08/15/85	PLATE MS4B	D202	17220	30680
5717	27	08/15/85	PLATE MS4B	D202	17220	30680
5718	27	08/15/85	PLATE MS4B	D202	17220	30680
5719	3	08/15/85	SORB MS4A	D129	16675	31125
5720	15	08/15/85	SORB HFIR	D172	16650	32835
5721	16	08/15/85	SORB HFIR	D177	16315	32555
5722	17	08/15/85	SORB MB	.	.	.
5723	2	08/15/85	SORB MS4	D157	16895	28195
5724	2	08/15/85	SORB MS4	D160	17000	27950
5725	2	08/15/85	GLASS MS4	D160	17000	27950
5726	2	08/15/85	WSUS MS4	D160	17000	27950
5727	2	08/15/85	PLATE MS4	D160	17000	27950
5728	1	08/15/85	SORB MS3	D67	17320	28000
5729	1	08/15/85	SORB MS3	D68	17200	28045
5730	1	08/15/85	GLASS MS3	D68	17200	28045
5731	1	08/15/85	WSUS MS3	D68	17200	28045
5732	1	08/15/85	PLATE MS3	D68	17200	28045
5733	17	08/15/85	GRAV MB	.	.	.
5734	10	08/15/85	PLATE K	.	24120	37920
5735	41	08/15/85	LAB	.	.	.

APPENDIX II. PRELIMINARY NOTES ON THE CHARACTERIZATION OF SEDIMENTS IN WHITE OAK CREEK BASIN.

In this survey, several hundred samples of gravel were collected from the basin. The White Oak Creek Basin occupies several different valleys each of which has different bedrock lithologies exposed. The Knox dolomite and the Chicamauga Limestone outcrop extensively in Bethel Valley, while the Conasauga Shale outcrops extensively along Melton Branch. The two valleys are separated by a steep outcrop of the Rome Formation. The southern valley wall of Melton valley is Knox dolomite. Previous studies (Cerling and Spalding, 1980; 1982) have shown that important properties of the sediments such as distribution coefficients (K_d) are quite different in different parts of the watershed. Because distribution coefficients can be very important in using the sediment concentrations of radionuclides to calculate the equilibrium water radionuclide concentrations, additional characterization of the sediments is required. This section discusses some observations on the mineralogy and sediment petrology of samples collected from the basin as part of this study.

Petrography. Nineteen sediment samples from the basin were examined in detail. Thin sections were made of each of these and observations were made on 78 to 154 grains for these samples. The petrographic categories were:

Chert

1. Silicified fossil and/or oolitic limestone: major silica replacement of fossiliferous and/or oolitic limestone
2. Silicified dolomite: major silica replacement of dolomite demonstrating a rhombohedral pattern
3. Chert: includes chert, chalcedony, microquartz, and megaquartz

Carbonate

4. Limestone: any carbonate not showing definite signs of fossils, oolites, or dolomite
5. Fossiliferous and/or oolitic limestone: any carbonate showing fossils and/or oolites without significant replacement by dolomite
6. Dolomite: a carbonate demonstrating high relief rhombohedrons

Mudstone

7. Silty shale: over 75% clays with a linear fabric such that birefringence between clay minerals is similarly oriented
8. Moderately sorted siltstone: moderate sorting with a large clay and lithic fraction, a poor linear fabric discernable
9. Poorly sorted siltstone: poor sorting with a large clay and lithic fraction, poor linear fabric discernable

Shale

10. moderately sorted siltstone: moderate sorting with less than 25% clays and lithics
11. poorly sorted siltstone: poor sorting with less than 25% clays and lithics

Other:

12. Heavy to complete Fe-Mn coatings: grains that could not be confidently identified due to extreme Fe/Mn coating
13. Unable to identify or classify: extremely unusual or odd fragments, including what appears to be metamorphic quartz

Estimates of the amount of Fe/Mn coatings were made by observation of the presence or absence of coating on either end of the longest and shortest axes of the sediment grains (four observations per grain). These were then tallied and averaged for each sediment type.

The high abundance of chert and limestone in Bethel Valley is consistent with the relatively low distribution coefficients for ^{90}Sr and ^{137}Cs . This difference is important in considering the extractable metal contents of sediments because limestone has different background concentrations of some metals than does shale.

Manganese and iron rich coatings were examined as well. Fe/Mn coatings formed on plate glass, glass beads, or PVC pipe were examined by X-ray diffraction and by the SEM. XRD patterns indicate that the phase formed was either todokorite or birnessite: diffraction patterns were indistinct because of the poorly crystalline nature of the coatings. Qualitative EDAX observations on the SEM suggested that the coatings contained Mn, Fe, Ni, Co, and Cr. Observations of extractable metals suggest that all of these are mobile in the basin to some degree.

Table 1. Studies at each of the localities in the 1985 survey of the White Oak Creek drainage.

	1	2	3	4	5	6
Site 1	X	X	X	X	X	X
Site 2	X	X	X	X	X	X
Site 3		X	X	X	X	X
Site 4		X	X	X	X	X
Site 5		X	X	X	X	
Site 6		X	X	X	X	
Site 7		X	X	X	X	
Site 8		X	X	X	X	
Site 9		X	X	X	X	
Site 10		X	X	X	X	X
Site 11		X	X	X	X	
Site 12		X	X	X	X	
Site 13		X	X	X	X	
Site 14		X	X	X	X	
Site 15		X	X		X	
Site 16		X	X		X	
Site 17		X	X		X	
Site 18			X			
Site 19			X			
Site 20		X	X			
Site 21 to Site 37			X			

1. Sampled with Manning pump for period 29 July to 15 August.
2. At least one water sample collected
3. Gravel sample collected. To be analyzed for radionuclides and heavy metals.
4. Organic rich ooze collected. To be analyzed for organic contaminants and heavy metal content.
5. Sorption experiment to determine active nature of contamination.
6. Glass beads deployed to examine Fe-Mn rates of deposition.

Table 2. Absolute concentrations (in mg/kg) in gravels as determined by three different extractants. Sample 5401 chosen for illustration.

extractant	Cd	Co	Cr	Cu	P	Sb	Se	Zn
NH ₂ OH·HCl	<.05	17.	.9	.47	9.	<2.	<2.	3.8
1 N HNO ₃	<.05	15.	6.2	3.6	13.	<2.	2.9	21.
EPA 1310	<.1	<.2	<.8	<.4	<6.	<2.	<2.	13.

Table 3. Comparison of extractants for metal contamination. Three uncontaminated indigenous gravels from near the HFIR locality were chosen to characterize the uncontaminated level for various metals. One sample below HFIR was chosen to represent a contaminated sample for which various extractants could be evaluated. The criteria used was the amount of increase in the contaminated sample compared to the uncontaminated sample. Given as values of C_c/C_b where C_c is the concentration of contaminated the sample and C_b is the concentration of the uncontaminated gravel.

extractant	Cd	Co	Cr	Cu	P	Sb	Se	Zn
NH ₄ OH·HCl	0.7	19.	22.	>11. ^a	38.	>3.	>3.	83.
1N HNO ₃	1.3	6.	12.	>27.	44.	>7.	6.	38.
EPA 1310	-b	-	-	-	>2.	-	-	28.

^a > below detection limit for C_b

^b - below detection limit for both C_c and C_b .

Table 4. Absorption of metals and radionuclides by gravel from 15 July to 15 August, 1985 in White Oak Creek.

site ¹ 137Cs	num. ²	locality ³	Cu	P	Zn	Mn	Fe	⁶⁰ Co	⁹⁰ Sr	
			parts per million						Beq per	
			Kg							
			Background = starting composition							
17 5401	MB		.5	9.	3.8	2900	1400	<5	<10	<5
17 5722	MB		.9		4.0	3100	1600	<5	<10	<5
17 5723	MB		.7		4.5	3000	1900	<5	<10	<5
White Oak Creek										
10 5684	JKL		.2	4.	2.5	2200	650	<5	<10	<5
11 5688	COOL		3.1	20.	76.	2100	840	<5	<10	<5
8 5689	MS2		.8	11.	12.	2300	870	<5	23	10
12 5690	3rd St		1.6	21.	62.	2200	960	160	220	26000
14 5692	MS2A		1.5	24.	51.	2000	880	150	340	11000
1 5729	MS3		2.1	28.	40.	2700	1400	110	350	7700
Melton Branch										
15 5720	HFIR+		1.0	8.	3.4	2600	1600	<5	<10	<5
16 5721	HFIR-		1.5	41.	49.	2300	1700	3100	<10	<6
3 5719	MS4A		2.0	45.	65.	2600	1600	4000	<10	26
2 5723	MS4		.8	30.	12	2400	1300	350	350	23
2 5724	MS4		1.1	30.	12	2500	1400	360	470	27
Other										
13 5691	NWT		<.2	6	3.9	2300	920	<5	510	49
9A 5693	SWSA4l		.4	6	2.9	2200	880	<5	12000	740
9B 5697	SWSA4u		.4	5	2.9	2200	970	<5	9800	54
7 5699	SWSA6		1.0	9	3.6	2500	1800	<5	190	<5
6 5700	6E		.8	9	3.2	2800	1600	49	100	5
5 5703	T345		1.1	10	3.3	2400	1600	120	<10	<5
4 5713	MS4B		1.1	14	4.6	3100	1500	<5	980	290

¹ Site number

² Sample number

³ Locality

TABLE 5. Extractable metals from gravels in White Oak Creek Watershed (in ppm).

Site	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe	Mg	Mn	Mo	Ni	P	V	Zn
1	497	39	1600	.3	6	16	2	1500	193	657	1.6	4.7	84	2.3	71
2	795	145	6300	<.1	11	11	1	2100	440	2300	1.6	4.8	130	2.0	90
3	630	158	3800	<.1	11	14	3	2100	412	1850	3.5	4.6	185	1.6	220
4	690	230	3000	<.1	11	6	2	3500	380	3000	0.7	5.0	40	1.7	19
5	1930	63	20300	<.3	8	6	2	2600	2100	807	<2.3	4.5	123	3.2	14
6	577	163	2600	<.1	14	1	1	1500	410	2500	0.7	4.9	34	2.2	4
7	653	160	3500	<.1	14	1	1	1600	330	4300	<.8	5.4	15	1.6	3
8	280	45	12000	.6	4	11	7	700	210	960	2.2	2.3	91	1.6	150
9	287	232	1600	<.1	7	1	2	1310	201	5400	7.3	280	19	1.2	10
10	648	108	2500	.1	10	2	1	2780	180	2120	0.4	2.8	25	3.4	20
11	240	20	18500	<.3	2	7	3	860	295	350	2.3	3.3	74	2.0	170
12	360	37	11000	.4	7	11	9	920	250	920	2.2	2.6	100	1.7	150
13	457	62	8000	.1	8	3	2	1500	203	1500	1.6	4.9	70	2.1	105
14															
15	740	210	3000	<.1	17	2	2	3400	370	3300	<.4	7.3	31	1.6	6
16	640	140	3500	<.1	12	11	15	3300	490	2400	4.7	7.3	340	2.3	340
17	520	200	3000	<.1	17	1	1	1400	220	2900	<.4	4.8	9	1.3	3
18	230	24	7900	.2	3	2	2	540	155	430	<.4	2.0	51		112
19	190	15	8600	.1	1	3	<1	780	130	210	<.4	2.2	73		48
20	190	48	980	<.2	11	<11	<1	495	44	1600	<1.0	<2.	<10	.9	4
21	275	40	2600	<.05	7	<11	<1	520	53	920	<.4	.8	4	1.0	4
22	530	210	2450	<.05	17	<1	<1	1450	310	2600	<.4	6.6	14		4
23	477	163	2400	<.05	12	5	7	1870	363	1800	3.8	4.9	143	1.6	207
24	697	257	2400	<.13	10	9	3	2700	380	6070		4.1	51		16
25	313	148	6600	<.05	4	6	1	2500	330	3100	<.4	2.5	59		15
26	427	170	2200	<.05	6	1	1	4400	430	1600		4.1	31	1.9	11
27	400	177	3400	<.05	10	2	2	2100	343	2800		3.3	37		9
28	430	153	3100	<.05	11	12	6	1500	373	2400	4.0	5.3	157	11	217
29	725	50	3150	.07	5	2	<1	1800	200	610	<.4	2.2	30		2
30		110	3100	<.05	11	1	2	2100	280	1100	<.4	3.0	20	2.5	4
31	325	52	2100	.18	6	12	5	1200	260	705	1.8	5.0	90	1.5	101
32	763	88	3300	<.05	17	1	1	1850	268	1150	.5	3.6	12	1.9	12
33	420	197	2200	<.05	11	<1	1	1500	413	1500	<.4	4.9	8	1.0	5
34	574	129	5100	<.05	11	<1	<1	1500	382	1230	.5	3.3	27	1.6	7
35	760	100	2500	<.05	14	<1	5	1100	280	2400		2.7	13		28
36	710	110	1900	<.05	10	1	<1	1600	190	1500		2.5	15		17
37		84	3000	<.05	19	1	<1	1700	230	1200	.4	3.7	12	1.7	10

TABLE 6. Preliminary characterization of sediments from White Oak Creek Watershed. Grains of indeterminate classification not included in this compilation.

Grains of indeterminate classification not included in this compilation.

Sample	Site	Kd		percent gravel			fraction Fe-Mn coated grains ¹
		⁹⁰ Sr	¹³⁷ Cs (ml/gm)	Chert	Carbonate	Shale	
Bethel Valley							
5426	8	14	700	21	30	37	11
5428	12	20	600	23	43	34	15
5434	10	22	131	75	4	21	73
5435	11	20	1100	13	47	40	18
5447	13	27	1600	49	23	28	46
Melton Branch							
5432	1	38	2200	40	0	60	27
5441	2	61	8500	4	2	94	44
5442	2	83	16000	1	2	97	43
5445	3	86	11000	1	2	97	31
5446	4	70	15000	0	0	100	36
5440	5	70	9900	3	30	67	38
5439	6	91	4600	0	0	100	37
5437	7	107	12000	1	0	99	73
5429	9	119	10300	3	0	97	87
5443	15	102	8200	1	2	97	37
5444	16	85	11000	0	0	100	54
5401	17	81	11000	0	2	98	3
5438	37	119	13000	0	0	100	75
5433	m*	37	5600	21	0	79	13

¹ fraction of total grain surface having some Fe-Mn coating. Determined as described in text.

m* 20 meters below confluence of Melton Branch with White Oak Creek.

TABLE 7. Estimated flux of radionuclides at important branch points in the White Oak Creek watershed. Only those localities whose volume can be estimated are included in this table.

SITE		Volume (10 ⁶ liters)	Flux (mCi: July 15 to August 15, 1986)		
			⁶⁰ Co	⁹⁰ Sr	¹³⁷ Cs
1	MS3	599	7.7	70.	40.
2	MS4	62	2.6	9.2	<.1
3	MS4A	52	25.	<.3	<.1
4	MS4B	10.8	<.1	3.5	<.1
5		7.8	.1	<.3	<.1
6		.27	<.1	0.5	<.1
7	SWSA 6	.97	<.1	0.5	<.1
8	MS2	499	<.1	3.8	<.1
9A	SWSA4	.46	<.1	1.6	<.1
12	3rd St.	529 . ¹	10.	39.	118.
13	NWT	9.2	<.1	1.6	<.1
14	2A	599. ³	10.5	68.	57.
other	SWSA 5	4	-	5.7	-

Kd (⁹⁰Sr) 81 ml/gm

K* (⁶⁰Co) 6.9 x 10³ ml/gm/d (see discussion in text)

K* (¹³⁷Cs) 9.4 x 10⁴ ml/gm/d(see discussion in text)

¹ estimated flow is measured flow at Monitoring Station 2 plus discharge of PWTP for period of study (30 x 10⁶ liters)

² this flow appears to be low and may have been on the order of 44 x 10⁶ liters for the study period. If so, the ⁹⁰Sr flux would be 7.6 mCi for the study period which is the figure used in the text.

³ estimated flow is the same as that at Monitoring Station 3. Measured flows appear to be too high at this locality.

⁴estimated ⁹⁰Sr from Site 2 - Site 3 - Site 4

Table 8. Organic phases considered in this study.

PP#	CAS#	NAME	DETECTION LIMIT
21A (11A)	88-06-2	2,4,6-trichlorophenol	<10
22A (08A)	59-50-7	p-chloro-m-cresol	<10
24A (01A)	95-57-8	2-chlorophenol	<10
31A (02A)	120-83-2	2,4-dichlorophenol	<10
34A (03A)	105-67-9	2,4-dimethylphenol	<10
57A (06A)	88-75-5	2-nitrophenol	<20
58A (07A)	100-02-7	4-nitrophenol	<50
59A (05A)	51-28-5	2,4-dinitrophenol	<50
60A (04A)	534-52-1	4,6-dinitro-2-methylphenol	<20
64A (09A)	87-86-5	pentachlorophenol	<50
65A (10A)	108-95-2	phenol	<10
	65-85-0	benzoic acid	<50
	95-48-7	2-methylphenol	<10
	108-39-4	4-methylphenol	<10
	95-95-4	2,4,5-trichlorophenol	<10
52B (34B)	87-68-3	hexachlorbutadiene	<10
53B (35B)	77-47-4	hexachlorocyclopentadiene	<10
54B (38B)	78-59-1	isophorone	<10
55B (39B)	91-20-3	naphthalene	<10
56B (40B)	98-95-3	nitrobenzene	<10
61B (41B)	62-75-9	N-nitrosodimethylamine	<50
62B (43B)	86-30-6	N-nitrosodiphenylamine	<20
63B (42B)	621-64-7	N-nitrosodipropylamine	<20
66B (13B)	117-81-7	bis(2-ethylhexyl)phthalate	<10
67B (15B)	85-68-7	benzyl butyl phthalate	<10
68B (26B)	84-74-2	di-n-butyl phthalate	<10
69B (29B)	117-84-0	di-n-octyl phthalate	<10
70B (70B)	84-66-2	diethyl phthalate	<10
71B (25B)	131-11-3	dimethyl phthalate	<10
72B (05B)	56-55-3	benzo(a)anthracene	<50
1B (01B)	83-32-9	acenaphthene	<10
5B (04B)	92-87-5	benzidine	<50
8B (46B)	120-82-1	1,2,4-trichlorobenzene	<10
9B (33B)	118-74-1	hexachlorobenzene	<10
12B (36B)	67-72-1	hexachloroethane	<10
18B (11B)	111-44-4	bis(2-chloroethyl)ether	<10
20B (16B)	91-58-7	2-chloronaphthalene	<10
25B (20B)	95-50-1	1,2-dichlorobenzene	<10
26B (21B)	541-73-1	1,3-dichlorobenzene	<10
27B (22B)	106-46-7	1,4-dichlorobenzene	<10
28B (23B)	91-94-1	3,3'-dichlorobenzidine	<50
35B (27B)	121-14-2	2,4-dinitrotoluene	<10
36B (28B)	606-20-2	2,6-dinitrotoluene	<10
37B (30B)	122-66-7	1,2-diphenylhydrazine	<20
39B (31B)	206-44-0	fluoranthene	<10
40B (17B)	7005-72-3	4-chlorophenyl phenyl ether	<10
41B (14B)	101-55-3	4-bromophenyl phenyl ether	<10

42B (12B)	39638-32-9	bis(2-chloroisopropyl)ether	<10
43B (10B)	111-91-1	bis(2-chloroethoxy)methane	<10
89P (01P)	309-00-2	aldrin	<10
90P (10P)	60-57-1	dieldrin	<10
91P (06P)	57-74-9	chlorodane	<10
92P (07P)	50-29-3	4,4'-DDT	<10
93P (08P)	72-55-9	4,4'-DDE	<10
94P (09P)	72-54-8	4,4'-DDD	<10
95P (11P)	115-29-7	Endosulfan I	<10
96P (12P)	115-29-7	Endosulfan II	<10
97P (13P)	1031-07-8	Endosulfan Sulfate	<10
73B (06B)	50-32-8	benzo(a)pyrene	<10
74B (07B)	205-99-2	benzo(b)fluoranthene	<10
75B (09B)	207-08-9	benzo(k)fluoranthene	<10
76B (18B)	218-01-9	chrysene	<10
77B (02B)	208-96-8	acenaphthylene	<10
78B (03B)	120-12-7	anthracene	<10
79B (08B)	191-24-2	benzo(ghi)perylene	<20
80B (32B)	86-73-7	fluorene	<10
81B (44B)	85-01-8	phenanthrene	<10
82B (19B)	53-70-3	dibenzeno(a,h)anthracene	<20
83B (37B)	193-39-5	indeno(1,2,3-cd)pyrene	<20
84B (45B)	129-00-0	pyrene	<10
	62-53-3	aniline	<10
	100-51-6	benzyl alcohol	<10
	106-47-8	4-chloroaniline	<10
	132-64-9	dibenzofuran	<10
	91-57-6	2-methylnaphthalene	<10
	88-74-4	2-nitroaniline	<10
	99-09-2	3-nitroaniline	<10
	100-01-6	4-nitroaniline	<10
98P(14P)	72-20-8	Endrin	<10
99P(15P)	7421-93-4	Endrin Aldehyde	<10
100P(16P)	76-44-8	Heptachlor	<10
101P(17P)	1024-57-3	Heptachlor Epoxide	<10
102P(02P)	319-84-6	Alpha-BHC	<10
103P(03P)	319-85-7	Beta-BHC	<10
104P(04P)	319-86-8	Delta-BHC	<10
105P(05P)	58-89-9	Gamma-BHC (lindane)	<10

TABLE 9. Chemistry of waters in White Oak Creek Basin. Cations, anions and silica in mmoles per liter, except alkalinity which is in meq per liter.

	Site	pH	Na	K	Ca	Mg	Alk	Cl	SO ₄	NO ₃	SiO ₂
5668	1	7.95	1.43	.06	1.04	.42	2.20	.28	.55	.97	.08
5667	2	8.15	1.87	.09	1.46	.54	2.10	.37	1.56	.40	.08
5666	3	7.66	.91	.12	2.74	1.06	1.10	.65	3.64	.21	.22
5665	4	7.79	.26	.05	1.10	.39	2.34	.20	.22	<.08	.04
5669	5	8.05	6.04	.05	.91	.43	7.00	.54	1.14	.37	.03
5670	6	7.44	3.87	.08	1.33	.46	5.97	.17	.07	.14	.08
5671	7	6.97	.17	.04	1.22	.33	3.72	.14	.05	<.08	.14
5663	8	7.65	.23	.04	.93	.39	1.90	.20	.24	.08	.08
5672	9	6.66	.61	.15	1.11	.62	6.10	.45	.10	<.08	.16
5661	10	7.49	.02	.02	.76	.65	2.76	<.03	<.05	<.08	.13
5664	11	7.88	.22	.05	.96	.38	1.90	.22	.26	<.08	.01
5662	12	7.60	.35	.04	.88	.36	1.98	.22	.24	.10	.08
5674	13	7.77	.21	.04	.85	.38	2.37	.22	.20	<.08	.01
5673	14	7.89	1.52	.07	.97	.39	2.29	.31	.95	.21	.08
5681	17	7.69	.20	.05	1.16	.22	2.98	.08	.14	<.08	.12

Figure 1. Quartz, radionuclide, Fe, and Mn content of streambed sediments in White Oak Creek as a function of size. (From Cerling and Spalding, 1982).

Figure 2. Schematic location map showing sampling sites in White Oak Creek Basin.

Figure 3. Absolute activities of ^{60}Co on gravel in White Oak Creek watershed. These represent the values on previously uncontaminated gravel placed in each locality for one month.

Figure 4. Absolute activities of ^{90}Sr on gravel in White Oak Creek watershed. These represent the values on previously uncontaminated gravel placed in each locality for one month.

Figure 5. Absolute activities of ^{137}Cs on gravel in White Oak Creek watershed. These represent the values on previously uncontaminated gravel placed in each locality for one month.

Figure 6. Profile of ^{60}Co in Melton Branch from HFIR to confluence with White Oak Creek. Each point for 1978 and for 1985 represents a three point running average.

Figure 7. Profile of ^{90}Sr in Melton Branch from HFIR to confluence with White Oak Creek. Each point for 1978 and for 1985 represents a three point running average.

Figure 8. Profile of ^{137}Cs in Melton Branch from HFIR to confluence with White Oak Creek. Each point for 1978 and for 1985 represents a three point running average.

Figure 9. Distribution of average extractable Al in stream sediments in White Oak Creek Basin. In general the values represent the average of three samples. Values marked with an asterisk represent average values that have one value two times greater than or less than the other values in the average.

Figure 10. As Figure 9, for extractable Ba.

Figure 11. As Figure 9, for extractable Ca.

Figure 12. As Figure 9, for extractable Cd.

Figure 13. As Figure 9, for extractable Co.

Figure 14. As Figure 9, for extractable Cr.

Figure 15. As Figure 9, for extractable Cu.

Figure 16. As Figure 9, for extractable Fe.

Figure 17. As Figure 9, for extractable Mg.

Figure 18. As Figure 9, for extractable Mn.

Figure 19. As Figure 9, for extractable Mo.

Figure 20. As Figure 9, for extractable Ni.

Figure 21. As Figure 9, for extractable P.

Figure 22. As Figure 9, for extractable V.

Figure 23. As Figure 9, for extractable Zn.

Figure 24. Diagram showing relative proportions of dissolved alkalinity, SiO_2 , and SO_4+Cl streams in White Oak Creek Basin.

Figure 25. Diagram showing relative proportions of dissolved alkalinity, NO_3 , and SO_4+Cl in streams in White Oak Creek Basin.

Figure 26. Diagram showing relative proportions of dissolved Na, Ca, and Mg in streams in White Oak Creek Basin.

Figure 27. A. Comparison of background and anthropogenic water concentrations of cations in White Oak Creek Basin. B. Comparison of background and anthropogenic water concentrations of anions in White Oak Creek Basin.

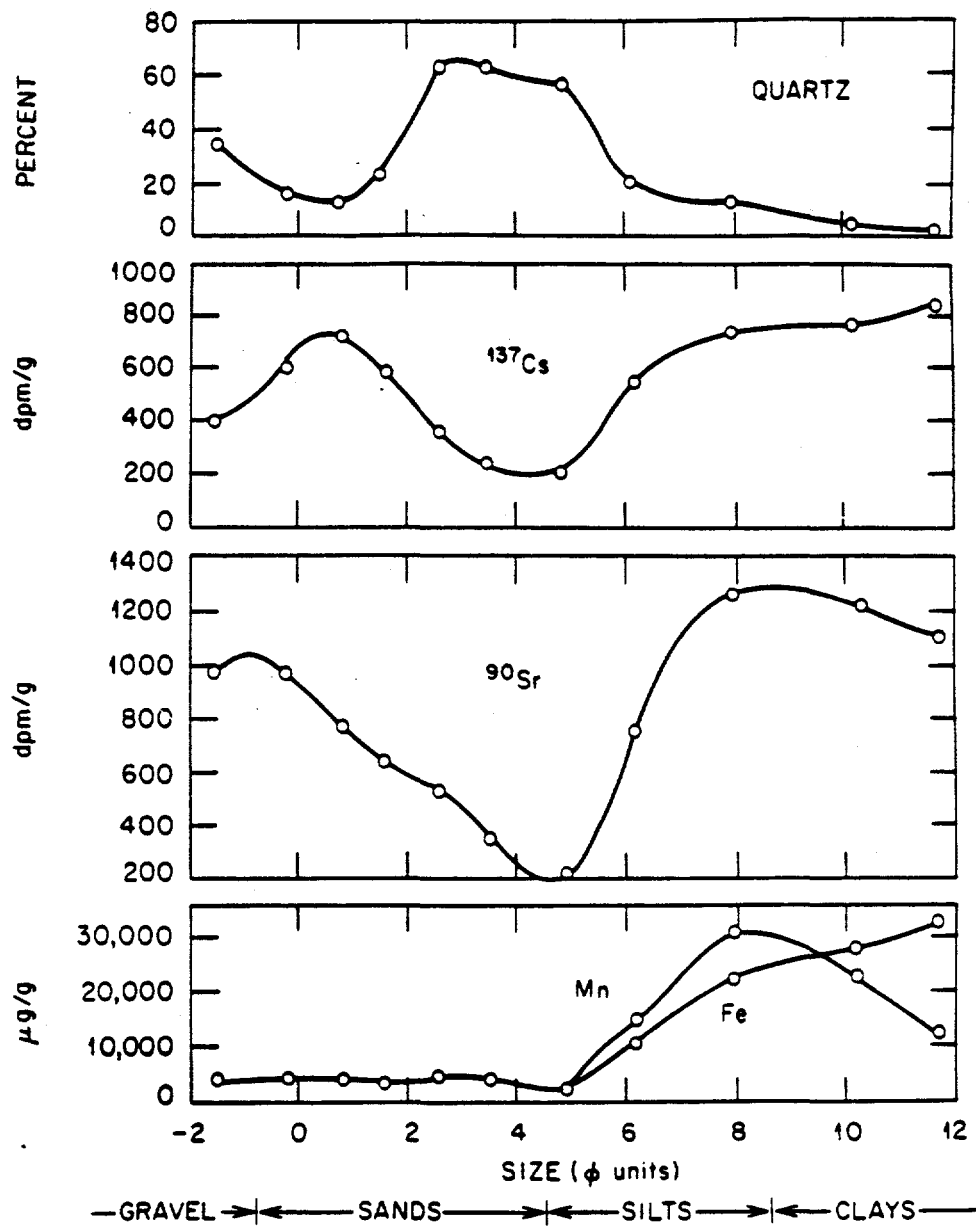


Figure 1. Quartz, radionuclide, Fe, and Mn content of streambed sediments in White Oak Creek as a function of size. (From Cerling and Spalding, 1982).

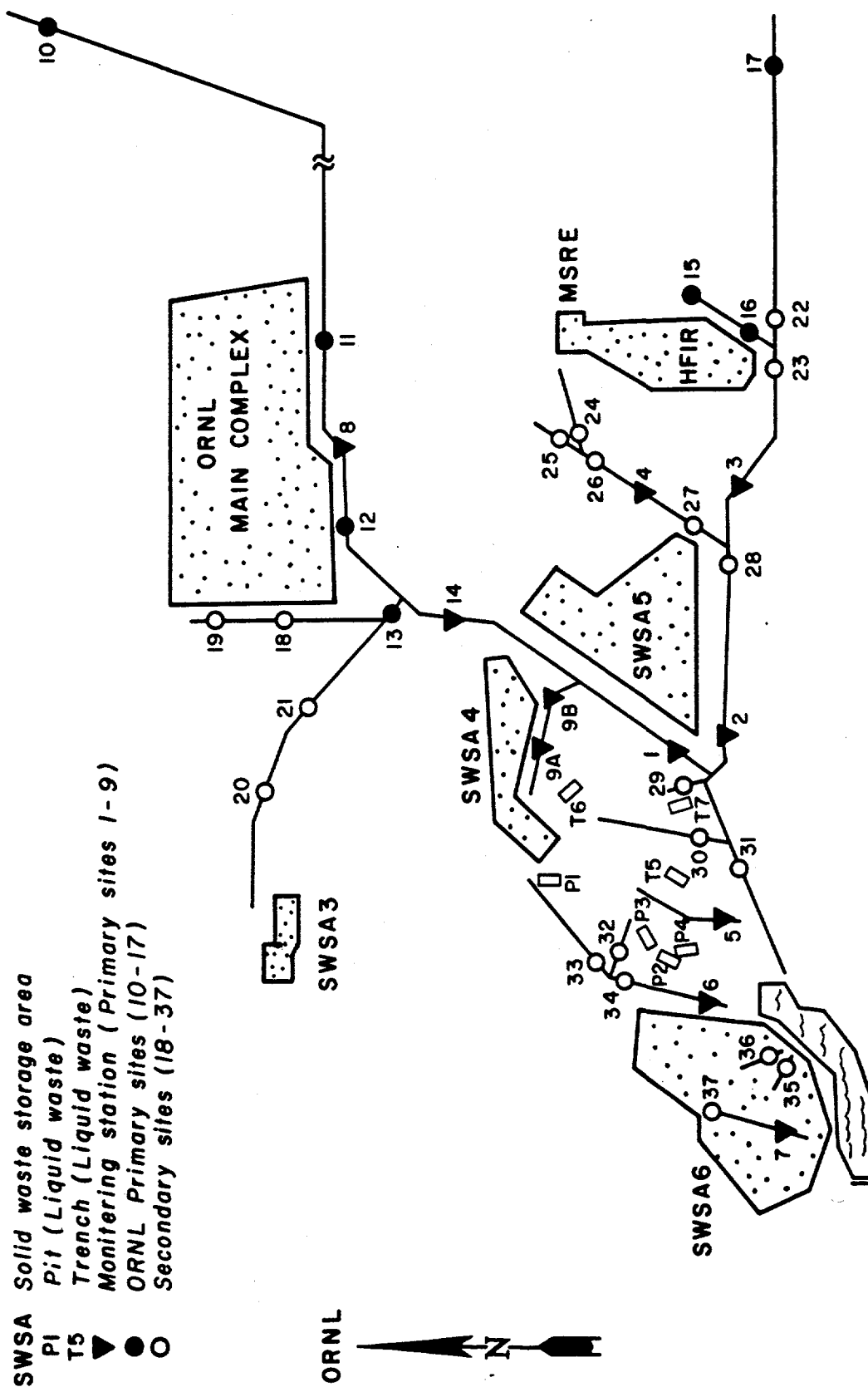


Figure 2. Schematic location map showing sampling sites in White Oak Creek Basin.

^{60}Co UPTAKE BY UNCONTAMINATED GRAVEL **19 July to 15 August, 1985** **(in Bq/kg)**

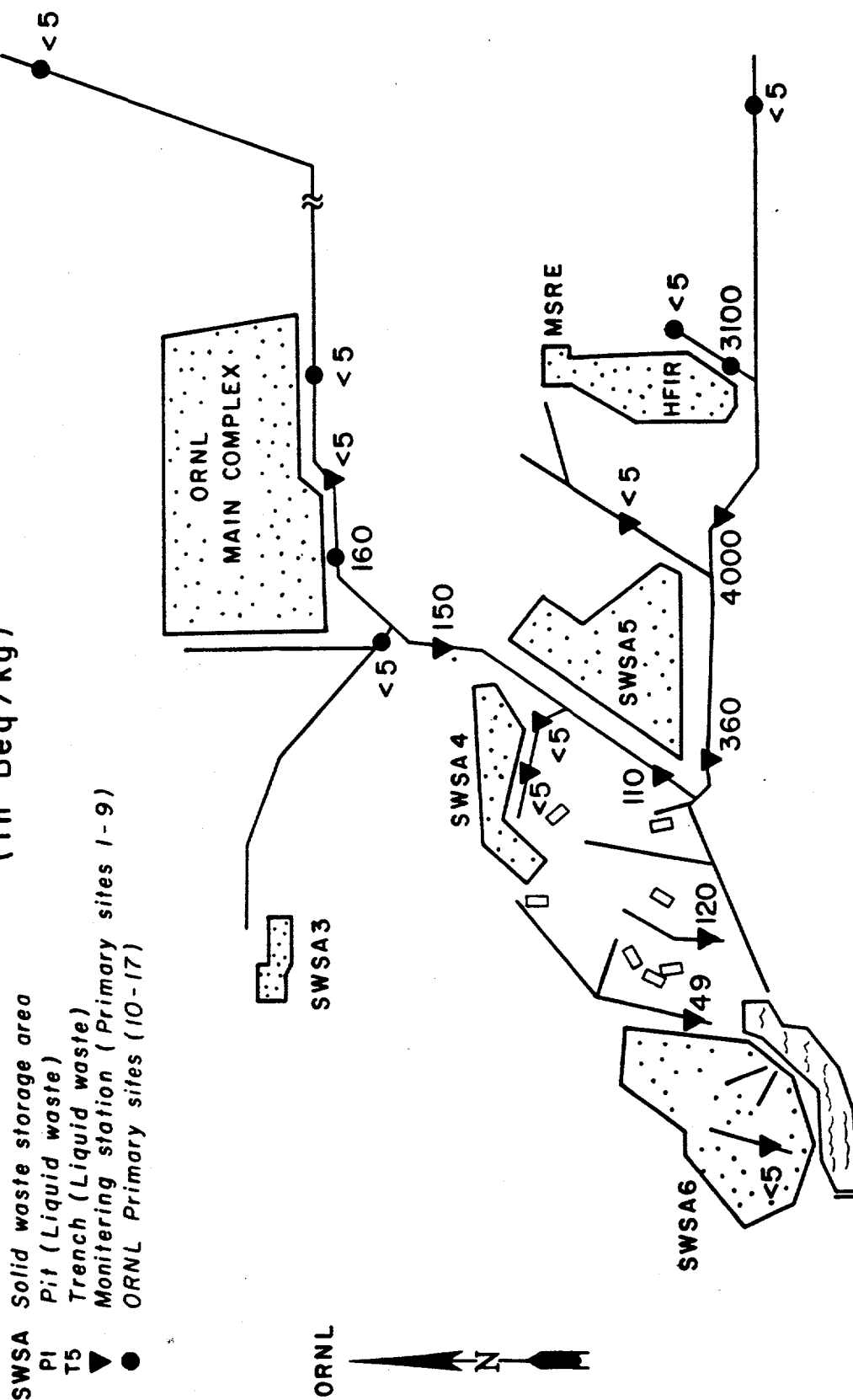


Figure 3. Absolute activities of ^{60}Co on gravel in White Oak Creek watershed. These represent the values on previously uncontaminated gravel placed in each locality for one month.

⁹⁰Sr UPTAKE BY UNCONTAMINATED GRAVEL **19 July to 15 August, 1985** **(in Bq/kg)**

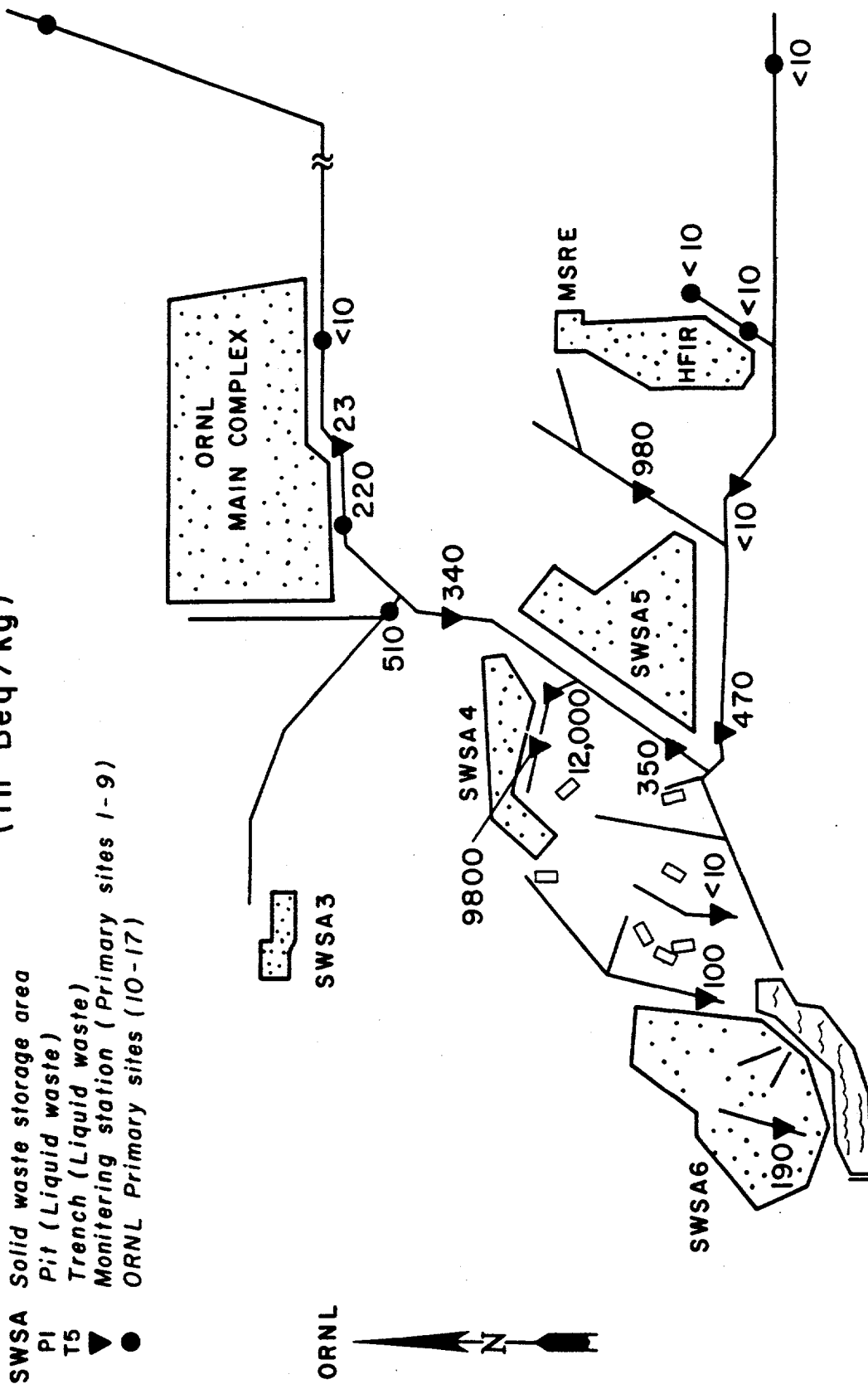


Figure 4. Absolute activities of ⁹⁰Sr on gravel in White Oak Creek watershed. These represent the values on previously uncontaminated gravel placed in each locality for one month.

¹³⁷Cs UPTAKE BY UNCONTAMINATED GRAVEL **19 July to 15 August, 1985** **(in Bq/kg)**

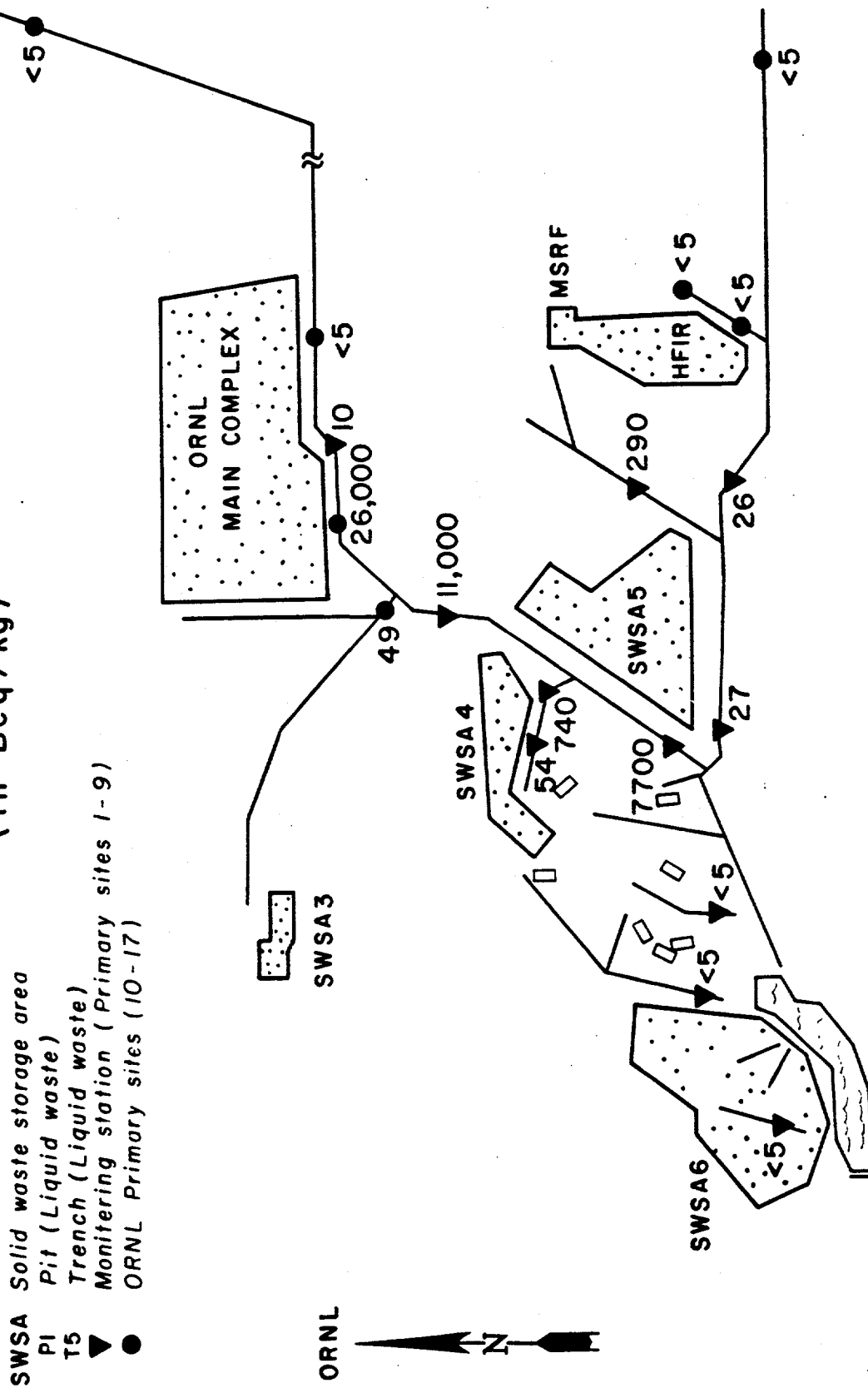


Figure 5. Absolute activities of ¹³⁷Cs on gravel in White Oak Creek watershed. These represent the values on previously uncontaminated gravel placed in each locality for one month.

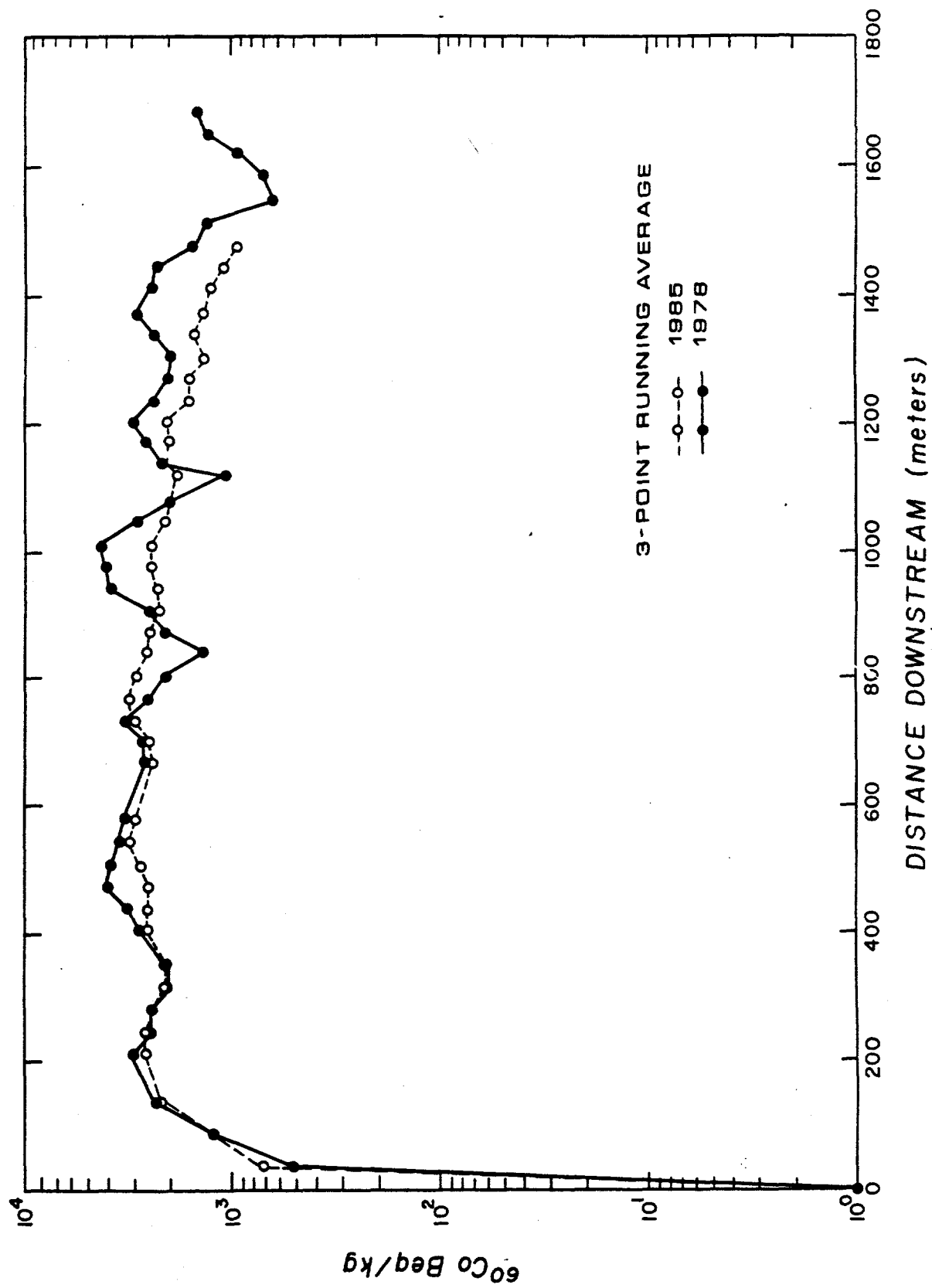


Figure 6. Profile of ^{60}Co in Melton Branch from HFIR to confluence with White Oak Creek. Each point for 1978 and for 1985 represents a three point running average.

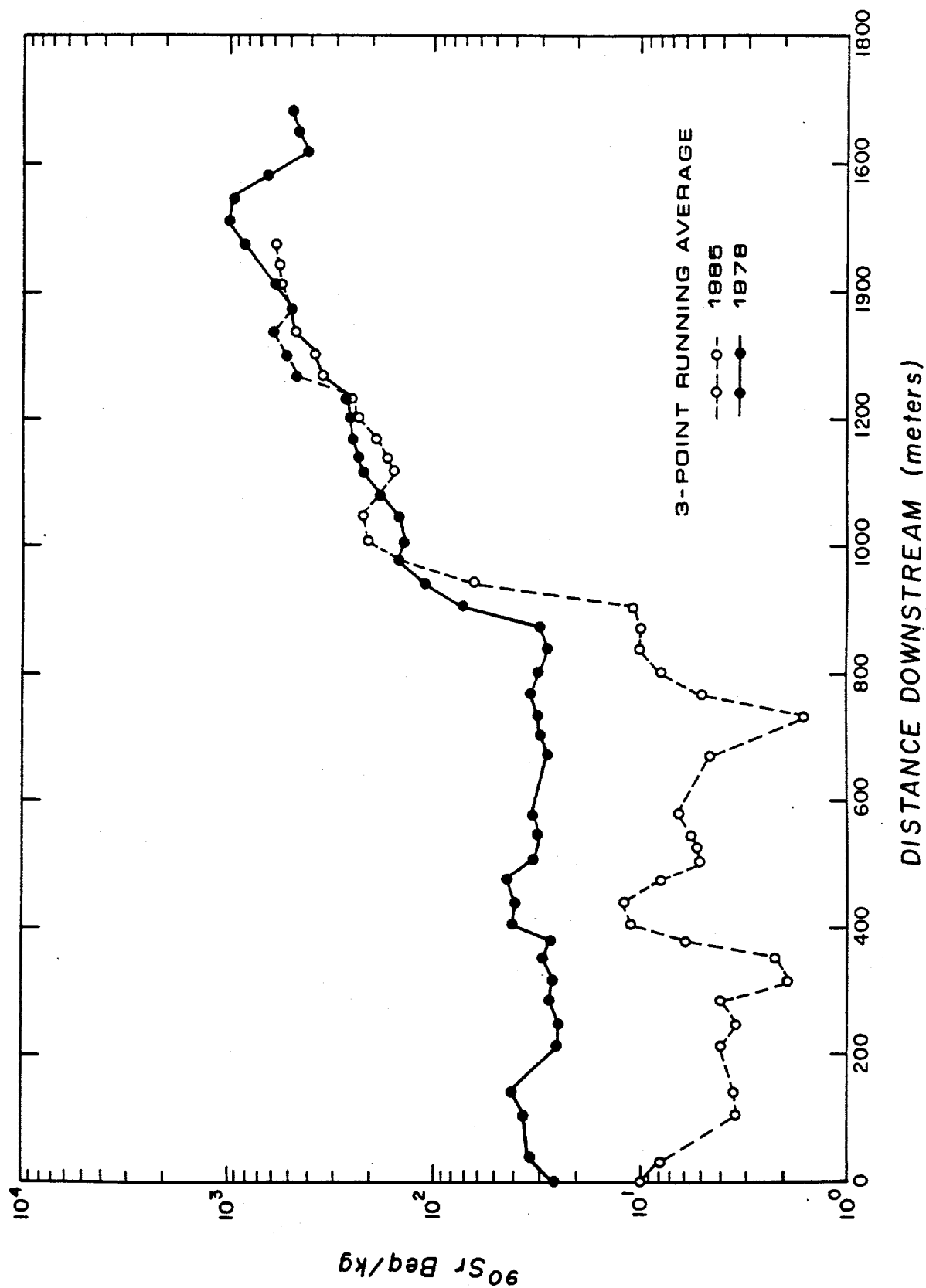


Figure 7. Profile of ^{90}Sr in Melton Branch from HFIR to confluence with White Oak Creek. Each point for 1978 and for 1985 represents a three point running average.

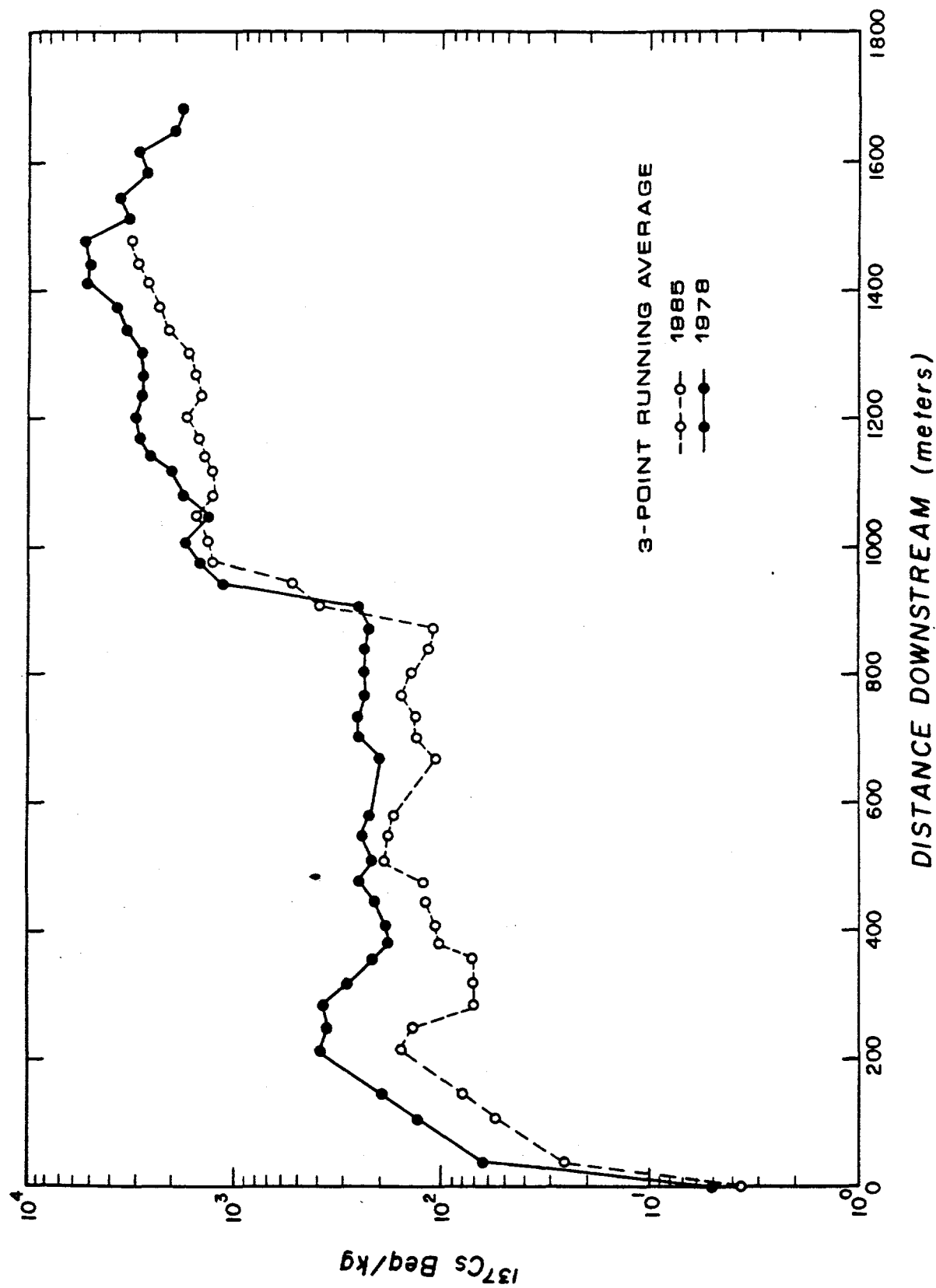


Figure 8. Profile of ^{137}Cs in Melton Branch from HFIR to confluence with White Oak Creek. Each point for 1978 and for 1985 represents a three point running average.

Extractable Al (ppm)

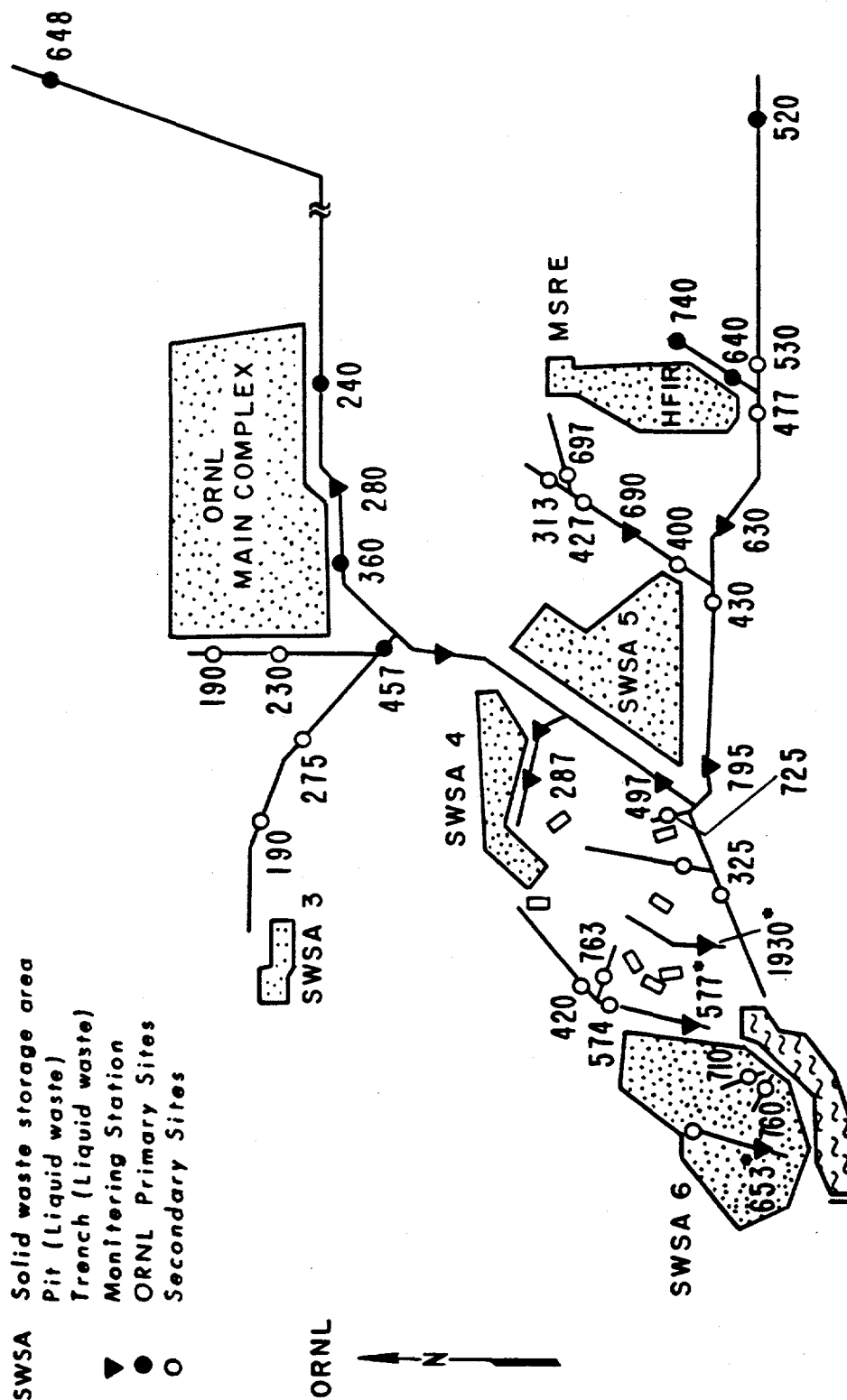
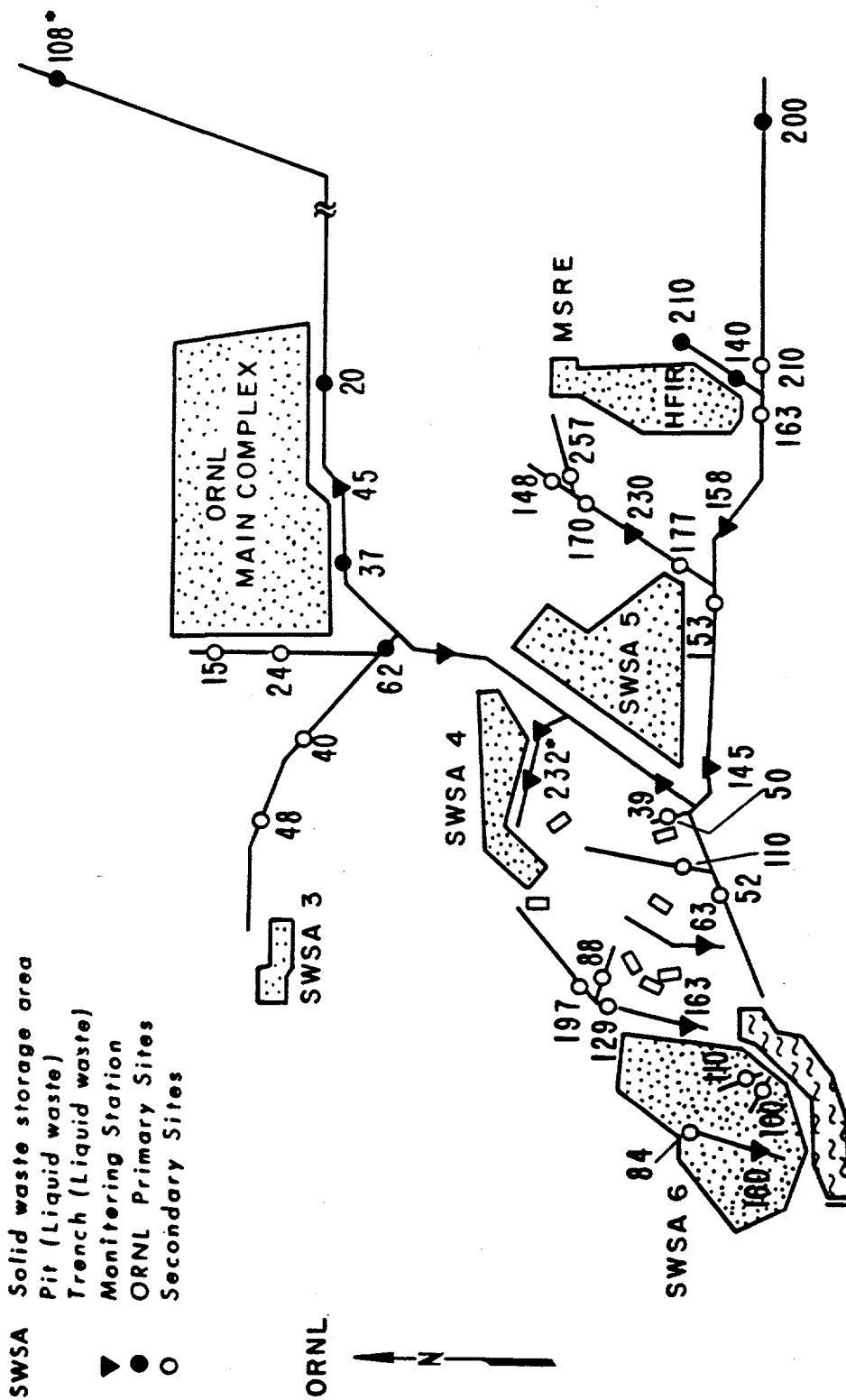


Figure 9. Distribution of average extractable Al in stream sediments in White Oak Creek Basin. In general the values represent the average of three samples. Values marked with an asterisk represent average values that have one value two times greater than or less than the other values in the average.

• - averages contain values >2x greater or less than other values in average

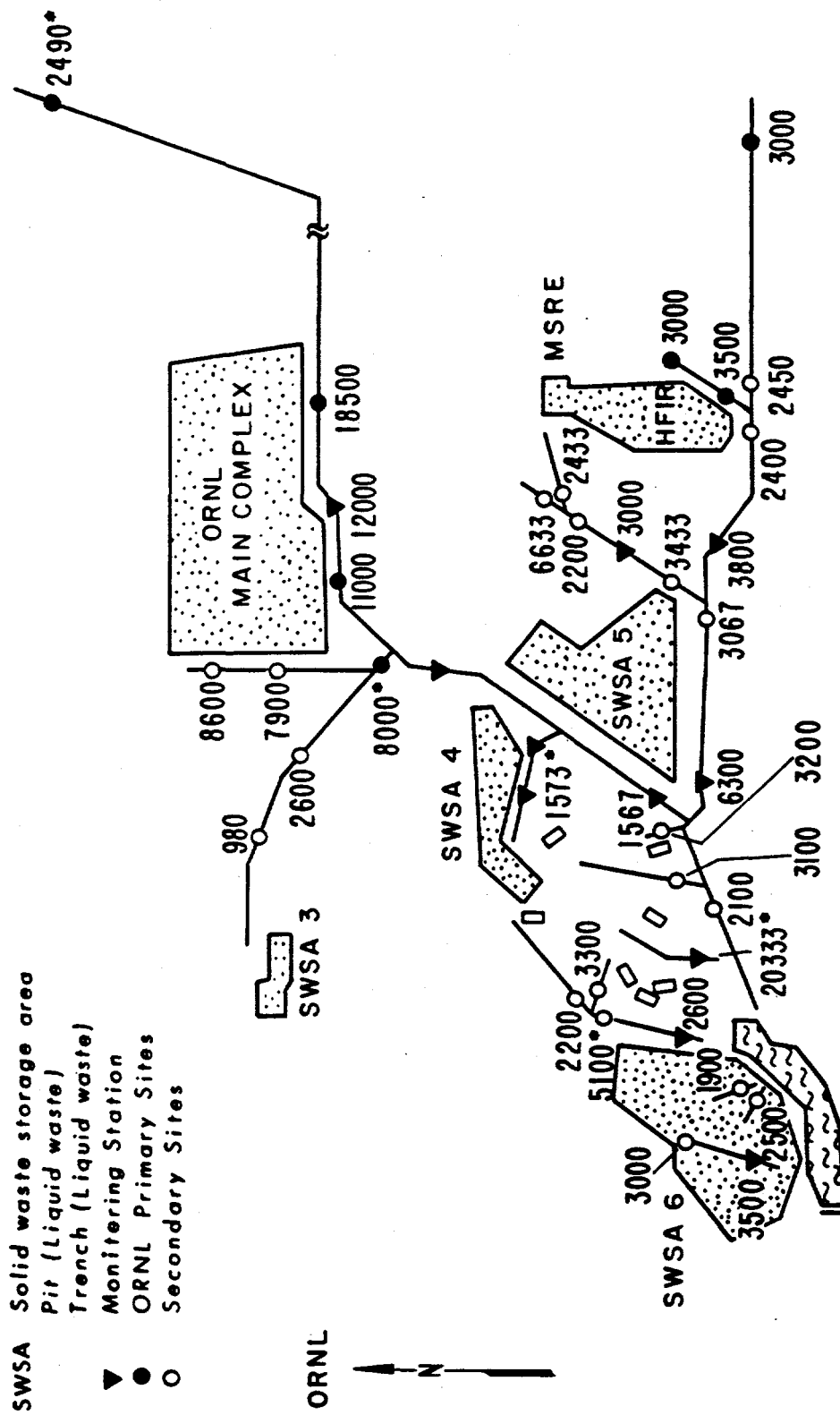
Extractable Ba (ppm)



* - averages contain values
> 2x greater or less than
other values in average

Figure 10. As Figure 9, for extractable Ba.

Extractable Ca (ug/g)



* - averages contain values
> 2 x greater or less than
other values in average

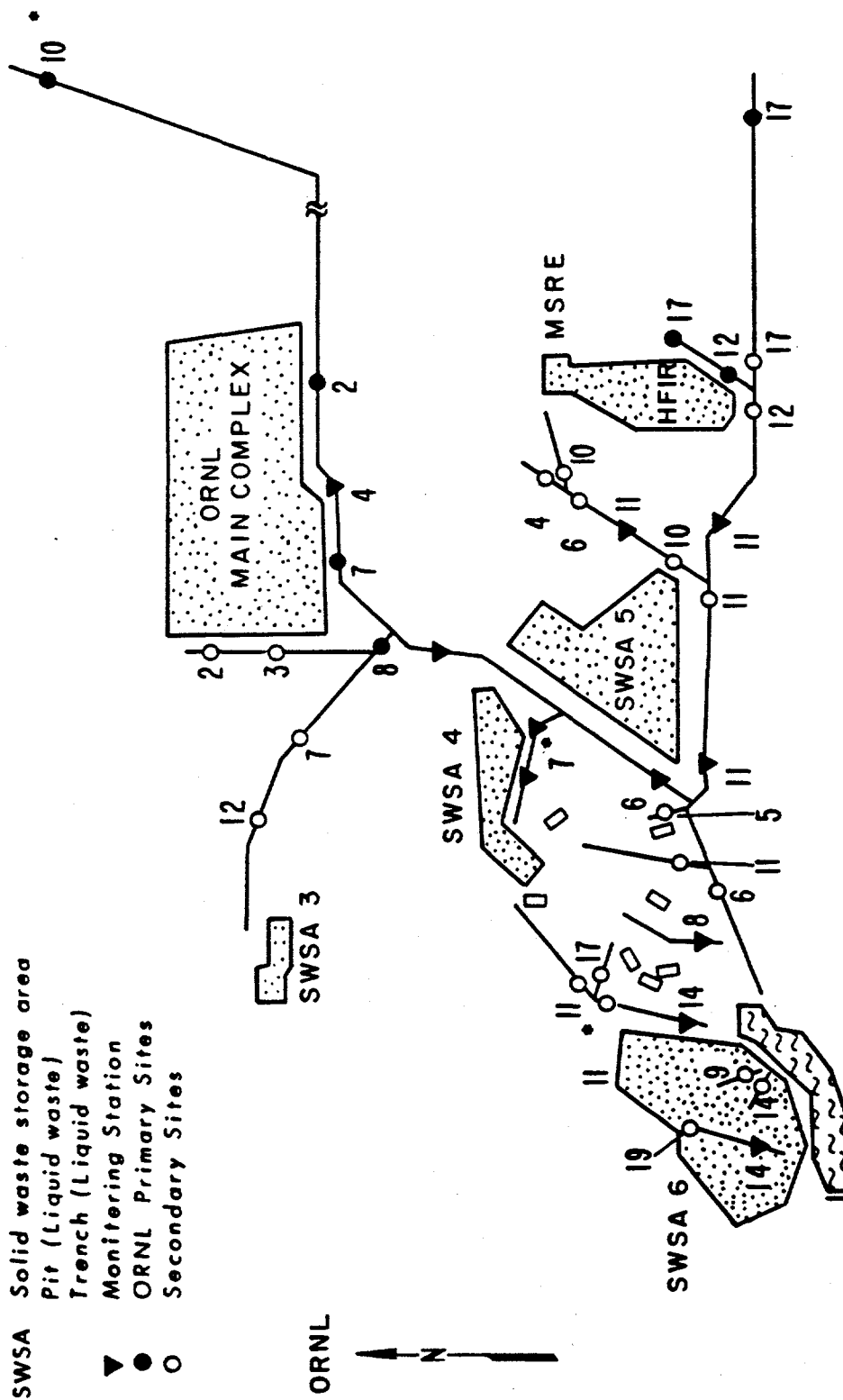
Figure 11. As Figure 9, for extractable Ca.

[illegible]

* -averages contain values
> 2x greater or less than
other values in average

Figure 12. As Figure 9, for extractable Cd.

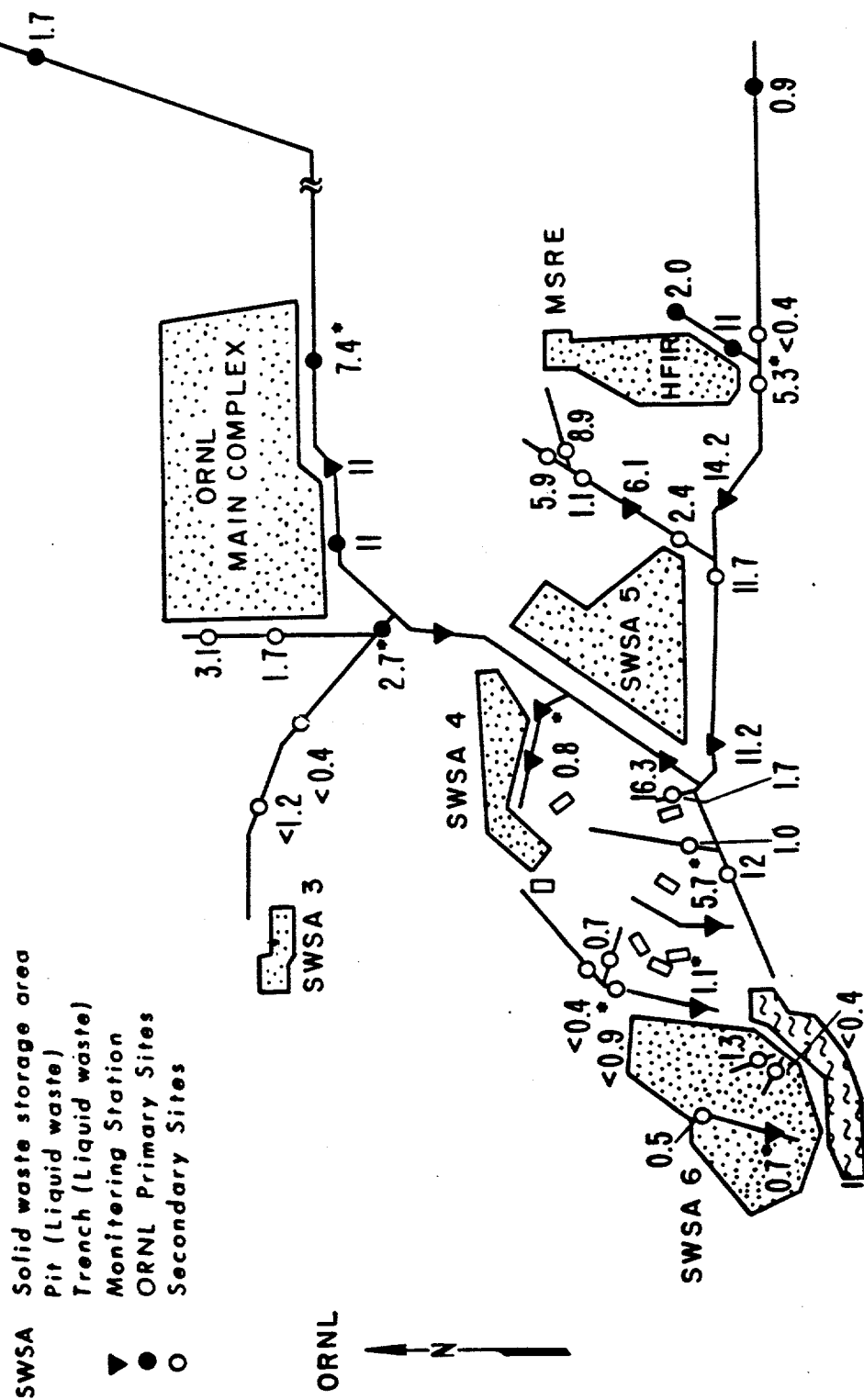
Extractable Co (ug/g)



* - averages contain values
>2x greater or less than
other values in average

Figure 13. As Figure 9, for extractable Co.

Extractable Cr (ug/g)



* -averages contain values
>2x greater or less than
other values in average

Figure 14. As Figure 9, for extractable Cr.

Extractable Cu (ug/g)

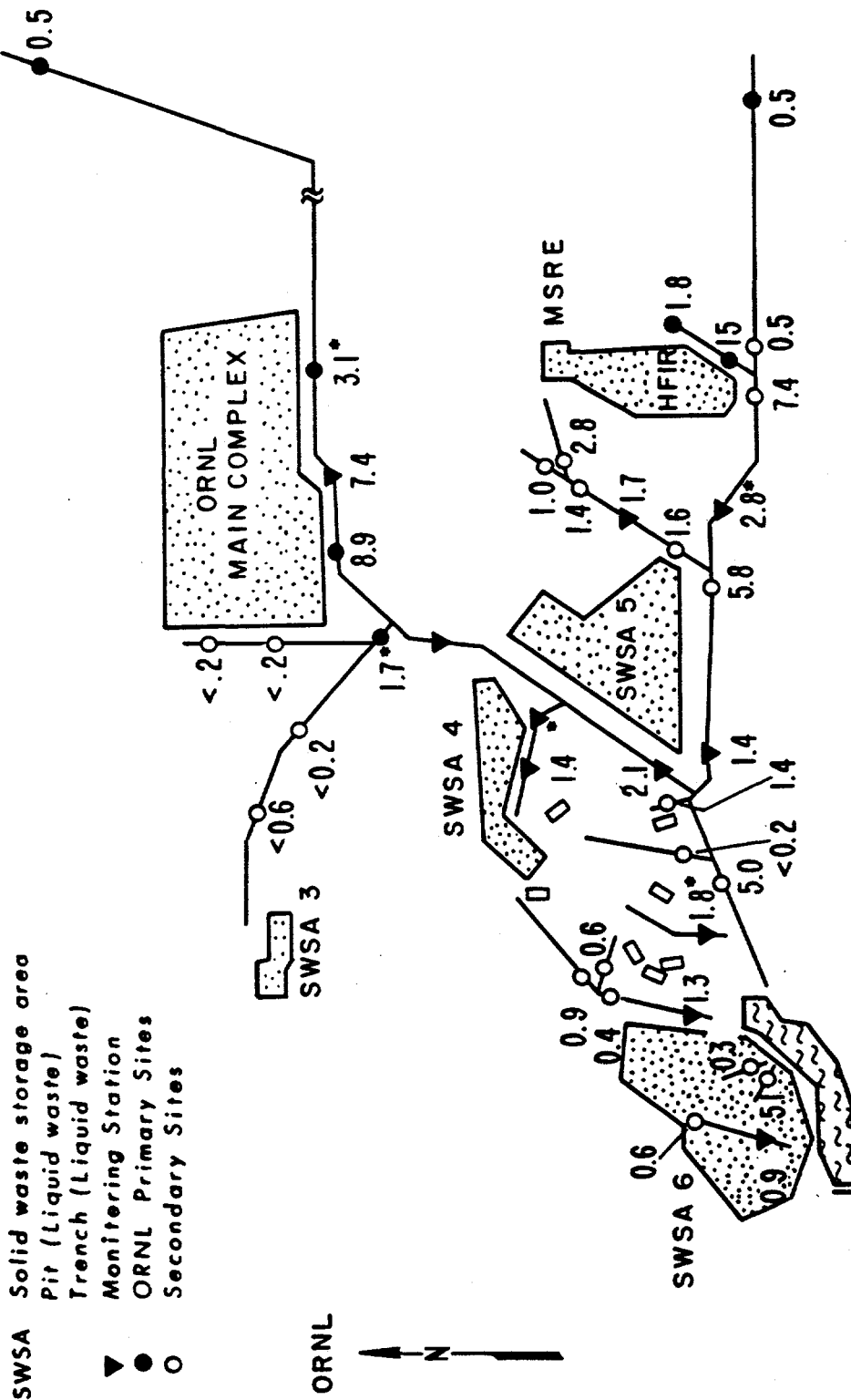
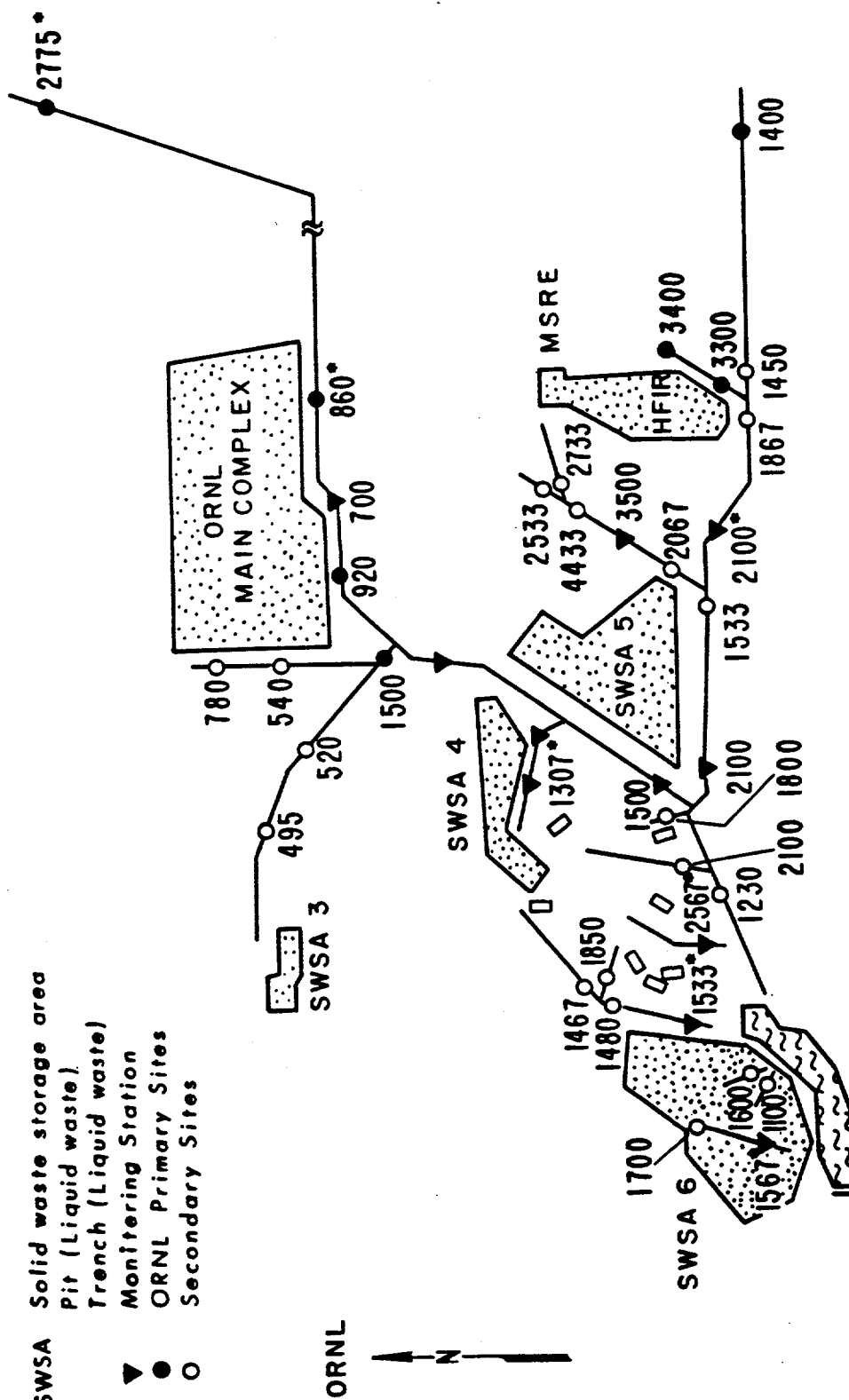


Figure 15. As Figure 9, for extractable Cu.

SWSA Solid waste storage area
▼ Pit (Liquid waste)
● Trench (Liquid waste)
○ Monitoring Station
○ ORNL Primary Sites
○ Secondary Sites



- averages contain values $> 2 \times$ greater or less than other values in average

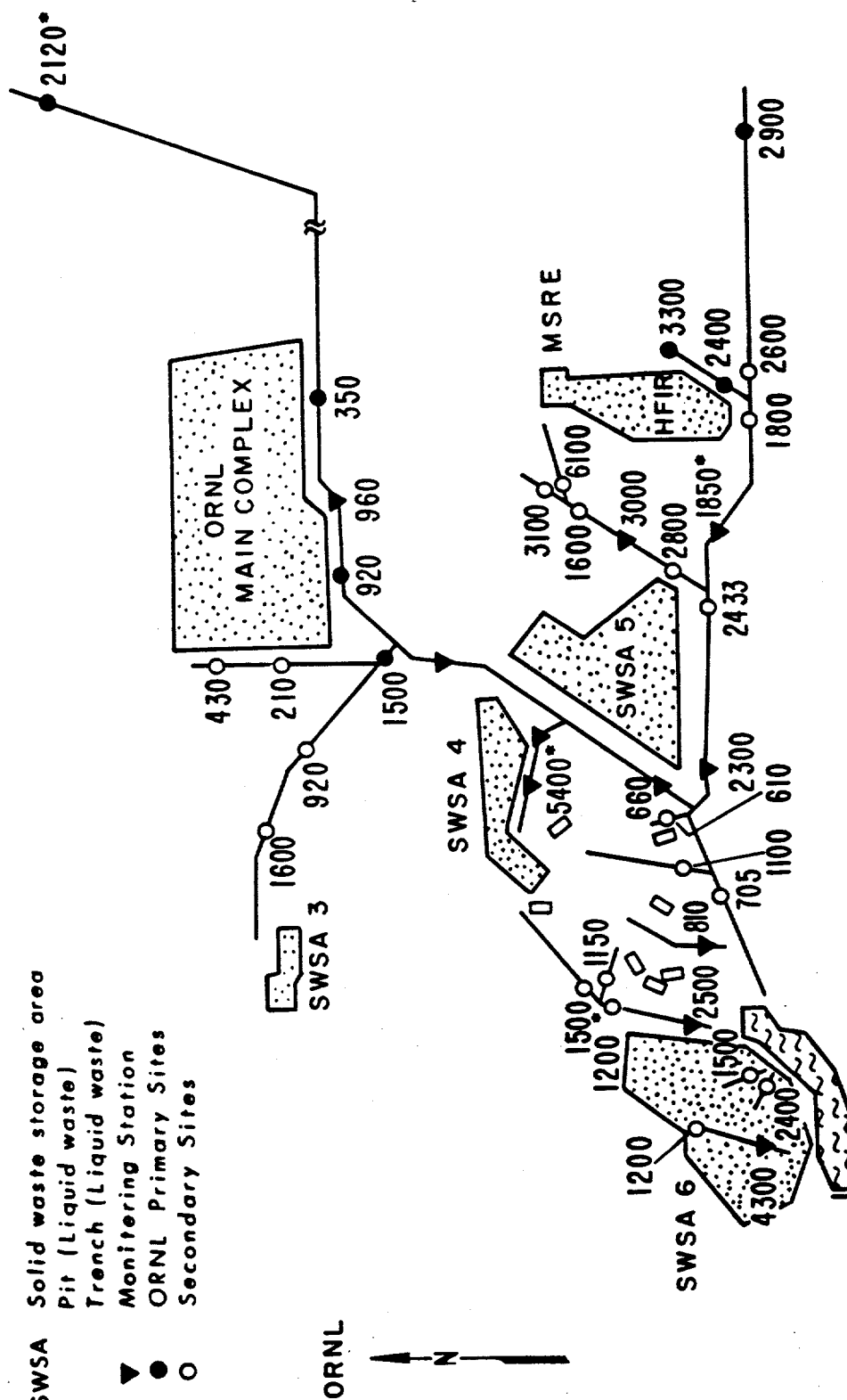
Figure 16. As Figure 9, for extractable Fe.

[illegible]

*** - averages contain values
>2x greater or less than
other values in average**

Figure 17. As Figure 9, for extractable Mg.

SWSA Solid waste storage area
▼ Pit (Liquid waste)
● Trench (Liquid waste)
○ Monitoring Station
○ ORNL Primary Sites
○ Secondary Sites



- averages contain values $> 2 \times$ greater or less than other values in average

Figure 18. As Figure 9, for extractable Mn.

ORNL

Legend:

- ▼ Monitoring Station
- ORNL Primary Sites
- Secondary Sites

Map Labels:

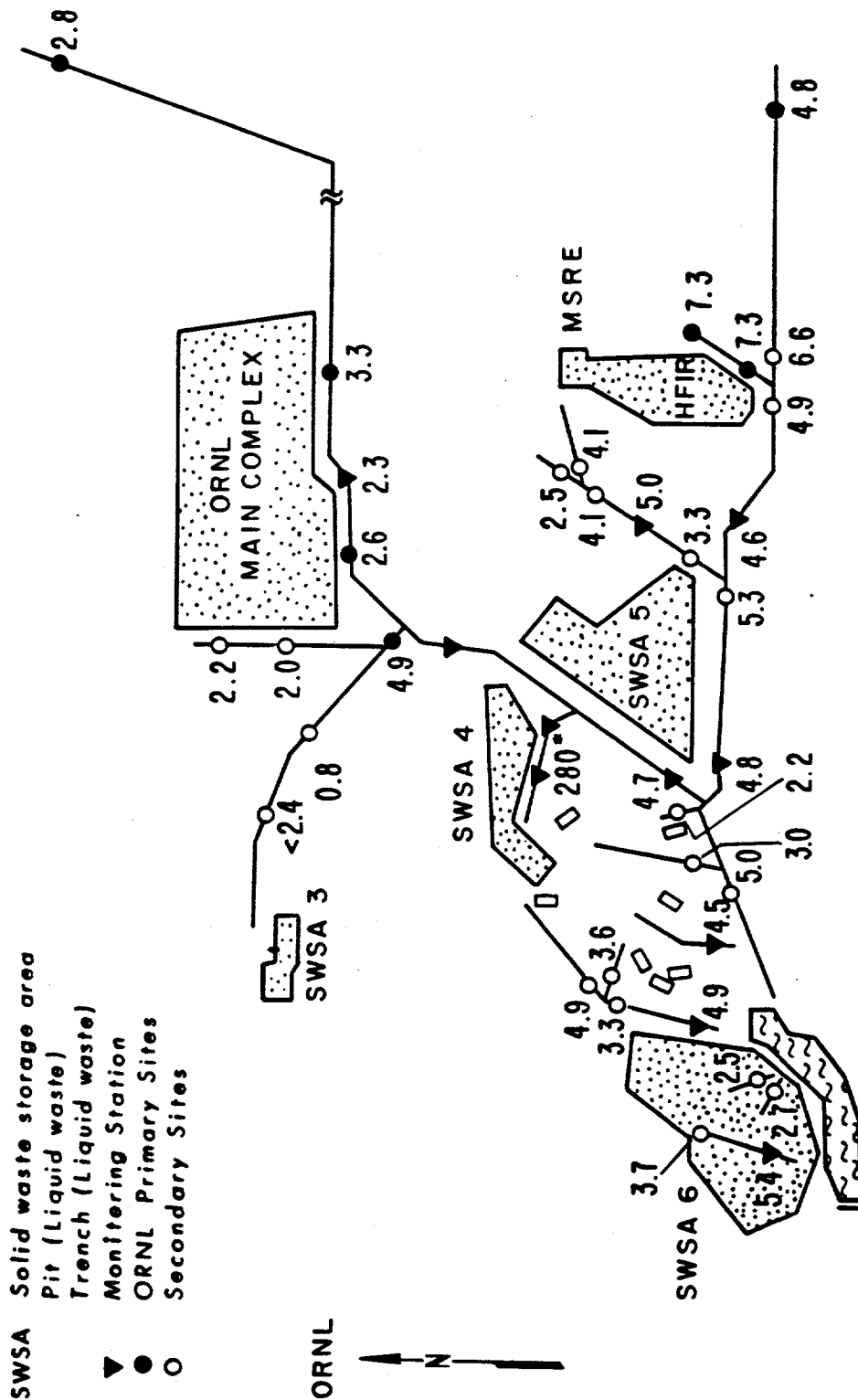
- SWSA 3
- SWSA 4
- SWSA 5
- SWSA 6
- ORNL MAIN COMPLEX
- MSRE
- HFIR

Data Points and Distances:

- Top left: 0.42
- Below SWSA 3: <0.4, <0.4, <0.4, <0.40, <1.2
- Between SWSA 3 and Main Complex: 1.6, 2.2, 2.2, 2.3
- Between Main Complex and SWSA 4: 1.6
- Between SWSA 4 and SWSA 5: 0.73
- Between SWSA 5 and SWSA 6: 1.6, 1.6, 1.8, <0.4, <2.3
- Between SWSA 6 and MSRE: 0.4, <0.48, <0.40, 0.68, 0.78
- Between MSRE and HFIR: <0.40, 0.65, 4.7
- Between HFIR and bottom right: <0.40, 3.8, <0.42, 4.0, 3.5
- Bottom right: <0.40

Figure 19. As Figure 9, for extractable Mo.

Extractable Ni (ug/g)



*-averages contain values
>2x greater or less than
other values in average

Figure 20. As Figure 9, for extractable Ni.

Extractable P (ug/g)

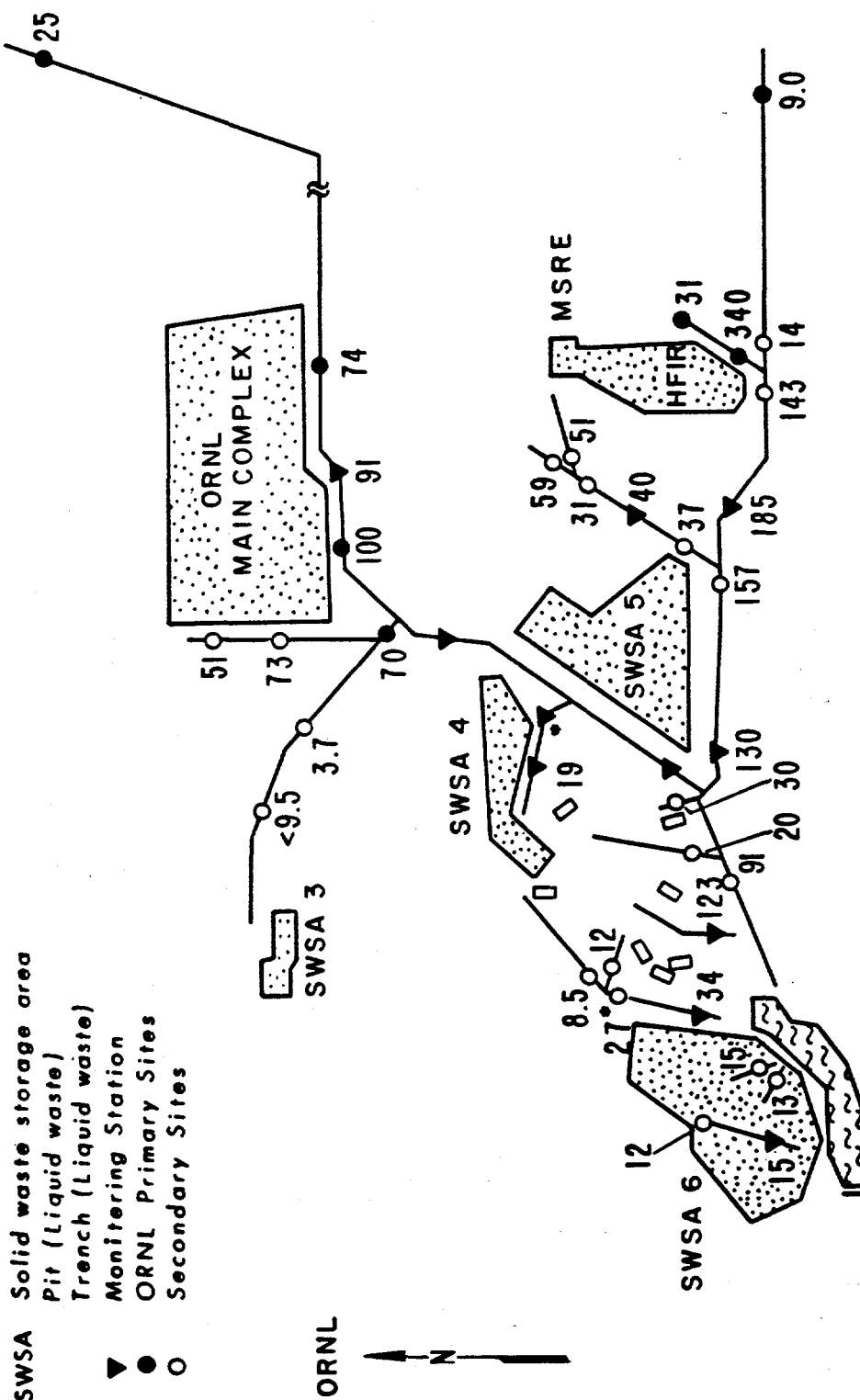


Figure 21. As Figure 9, for extractable P.

Legend:

- SWSA Solid waste storage area
- Pit (Liquid waste)
- Trench (Liquid waste)
- Monitoring Station
- ORNL Primary Sites
- Secondary Sites

Map Labels:

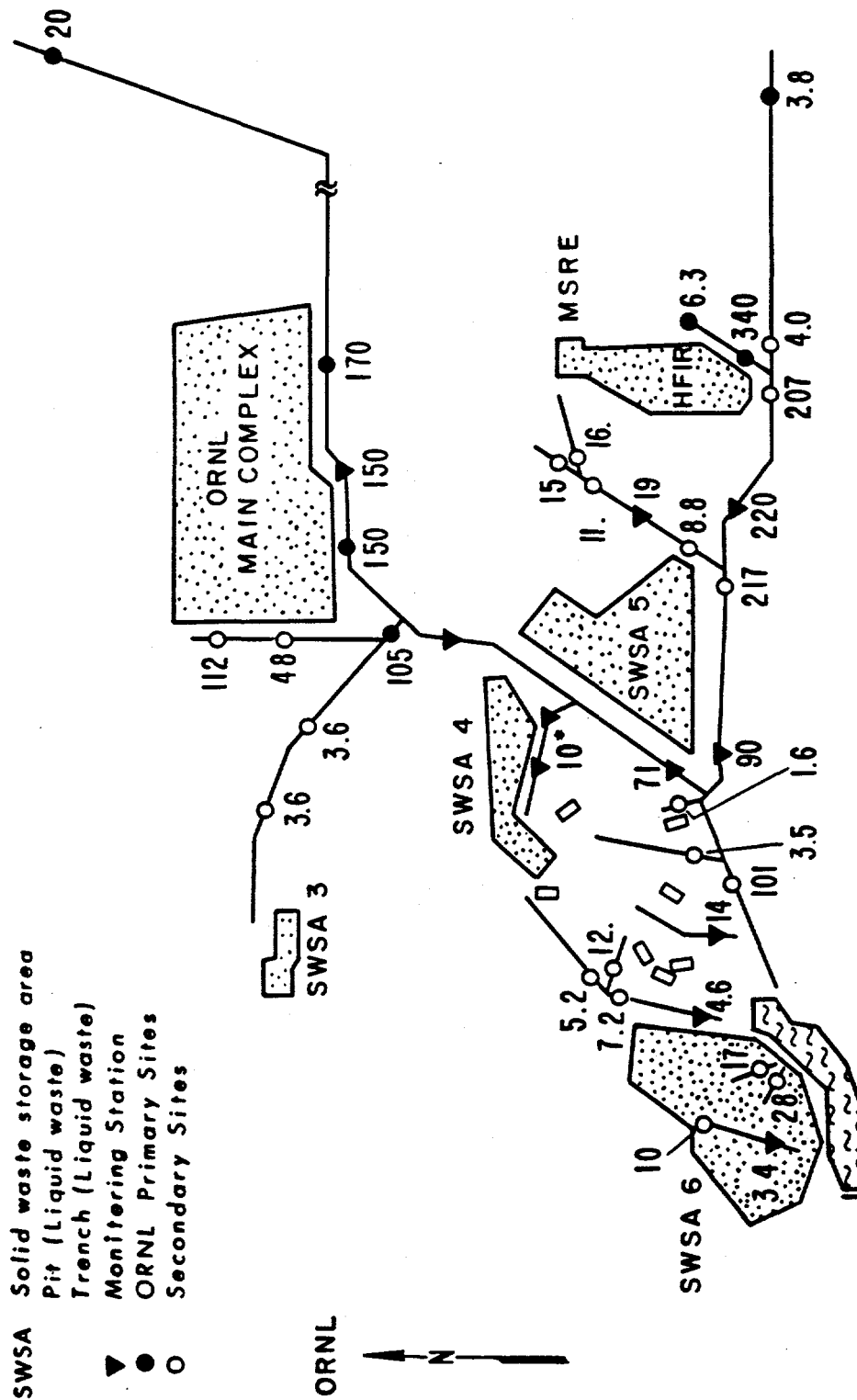
- ORNL
- ORNL MAIN COMPLEX
- SWSA 3
- SWSA 4
- SWSA 5
- SWSA 6
- MSRE
- HFIR

Distances (miles):

- 0.86 (from SWSA 3 to ORNL Main Complex)
- 1.0 (from SWSA 3 to SWSA 4)
- 1.7 (from ORNL Main Complex to SWSA 4)
- 2.1 (from ORNL Main Complex to SWSA 5)
- 1.6 (from SWSA 4 to SWSA 5)
- 1.2 (from SWSA 4 to SWSA 6)
- 2.3 (from SWSA 5 to SWSA 6)
- 1.5 (from SWSA 6 to SWSA 5)
- 2.5 (from SWSA 6 to SWSA 4)
- 1.0 (from SWSA 6 to SWSA 3)
- 1.6 (from SWSA 6 to SWSA 4)
- 1.9 (from SWSA 6 to SWSA 5)
- 3.2 (from SWSA 6 to SWSA 3)
- 2.2 (from SWSA 6 to SWSA 4)
- 1.7 (from SWSA 5 to SWSA 6)
- 1.1 (from SWSA 5 to SWSA 4)
- 1.6 (from SWSA 5 to SWSA 3)
- 2.0 (from SWSA 5 to SWSA 6)
- 1.3 (from SWSA 5 to SWSA 4)
- 1.6 (from SWSA 5 to SWSA 3)
- 2.3 (from SWSA 5 to SWSA 4)
- 1.6 (from SWSA 5 to SWSA 6)
- 1.7 (from SWSA 5 to SWSA 3)
- 1.9 (from SWSA 5 to SWSA 4)
- 2.0 (from SWSA 5 to SWSA 6)
- 2.5 (from SWSA 5 to SWSA 3)
- 3.4 (from SWSA 5 to SWSA 4)

Figure 22. As Figure 9, for extractable V.

Extractable Zn (ug/g)



* - averages contain values
 >2x greater or less than
 other values in average

Figure 23. As Figure 9, for extractable Zn.

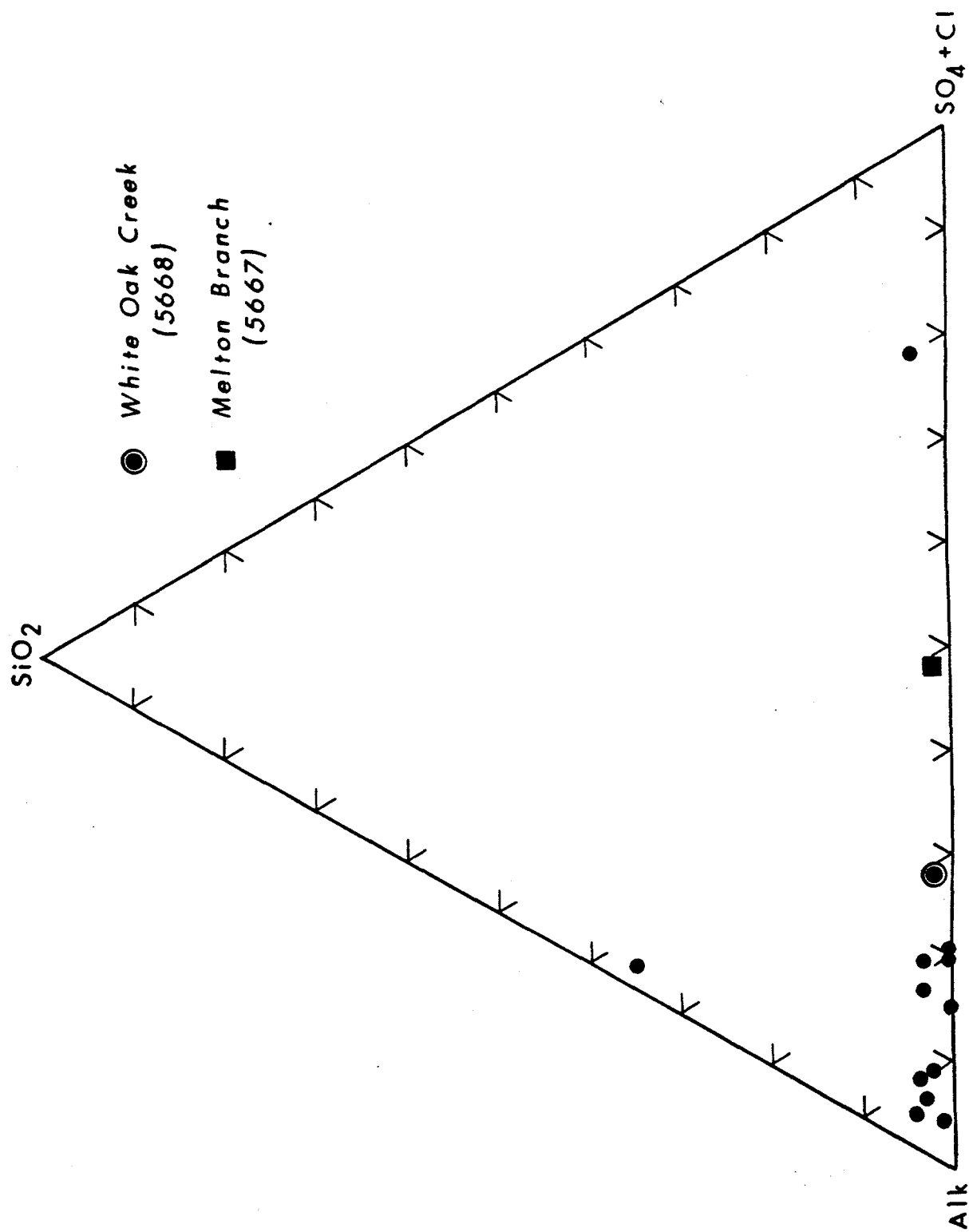


Figure 24. Diagram showing relative proportions of dissolved alkalinity, SiO₂, and SO₄+Cl streams in White Oak Creek Basin.

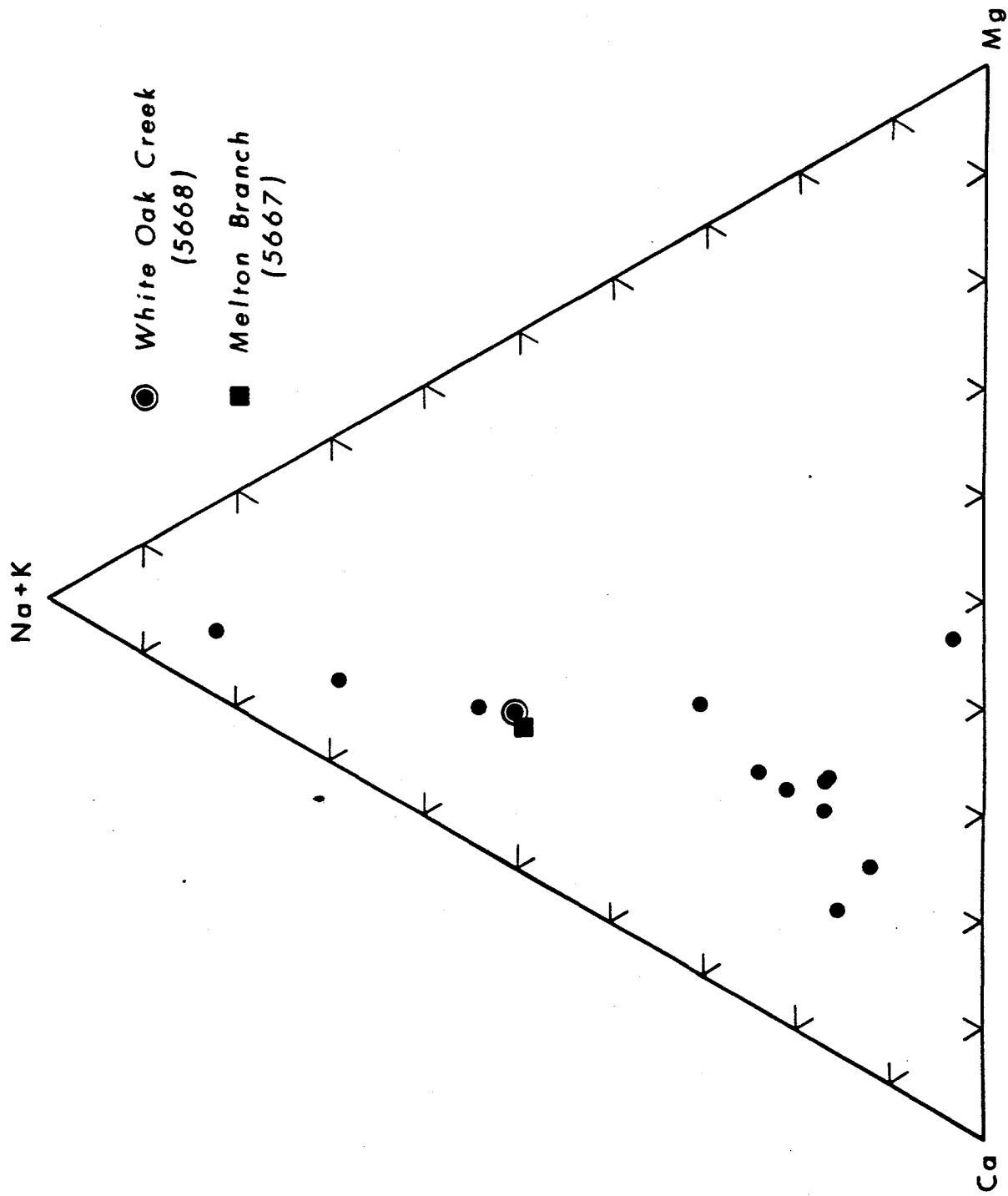


Figure 26. Diagram showing relative proportions of dissolved Na, Ca, and Mg in streams in White Oak Creek Basin.

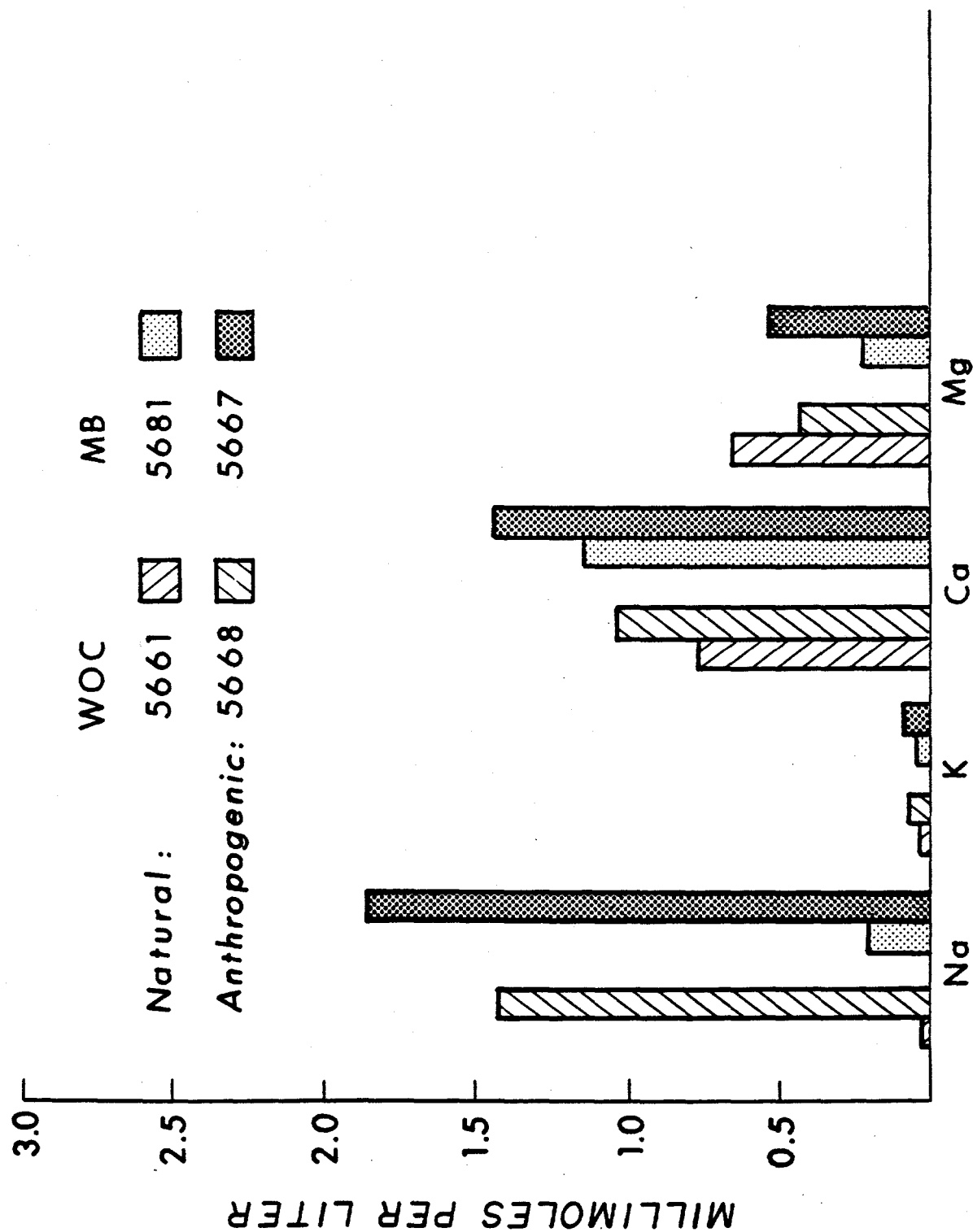


Figure 27. A. Comparison of background and anthropogenic water concentrations of cations in White Oak Creek Basin.

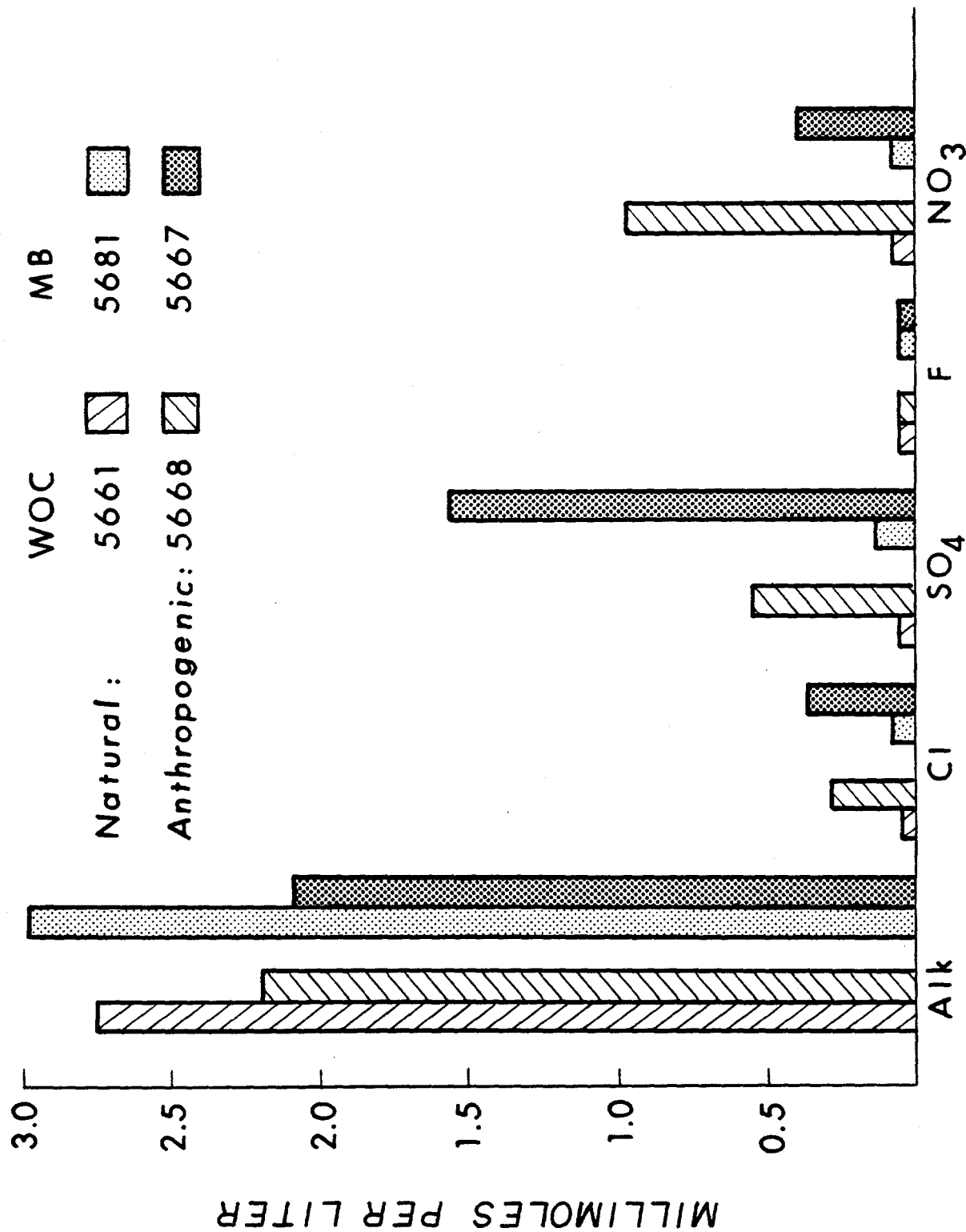


Figure 27.B. Comparison of background and anthropogenic water concentrations of anions in White Oak Creek Basin.